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GEOHYDROLOGIC RECONNAISSANCE
AND GROUND WATER MODEL EVALUATION
OF
THE SAN SEBASTIAN MARSH AREA
IMPERIAL COUNTY, CALIFORNIA

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* THERMAL
EXPLORATION

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GEOHYDROLOGIC RECONNAISSANCE
AND GROUNDWATER MODEL EVALUATION
OF
THE SAN SEBASTIAN MARSH AREA,
IMPERIAL COUNTY, CALIFORNIA

INTRODUCTION

This report presents the results of a geohydrologic investigation of the San Sebastian Marsh wetland area associated with the lower San Felipe Creek drainage area in Imperial County, California. The investigation was done under contract number YA-553-RFPO-29 for the U.S. Department of Interior, Bureau of Land Management, Denver, Colorado, under the supervision of the Riverside, California District Office.

The purpose of this investigation was to evaluate the geohydrology of the lower San Felipe Creek drainage area in order to determine baseline conditions in the San Sebastian Marsh wetland area. The wetland area provides habitat for two species which are on the recommended sensitive species list (Mr. Duane Winters) U.S. Bureau of Land Management, Riverside District Office, personal communication). Future ground water development in the lower San Felipe Creek area for agricultural development or other uses may significantly affect the wetland area. Therefore, the ultimate objective of studying the geohydrology is to provide estimates of water level declines in the San Sebastian Marsh area resulting from projected pumping and to determine how the declines would affect the marsh. To assist the accomplishment

of this objective the construction, calibration, and verification of a ground water flow model is planned.

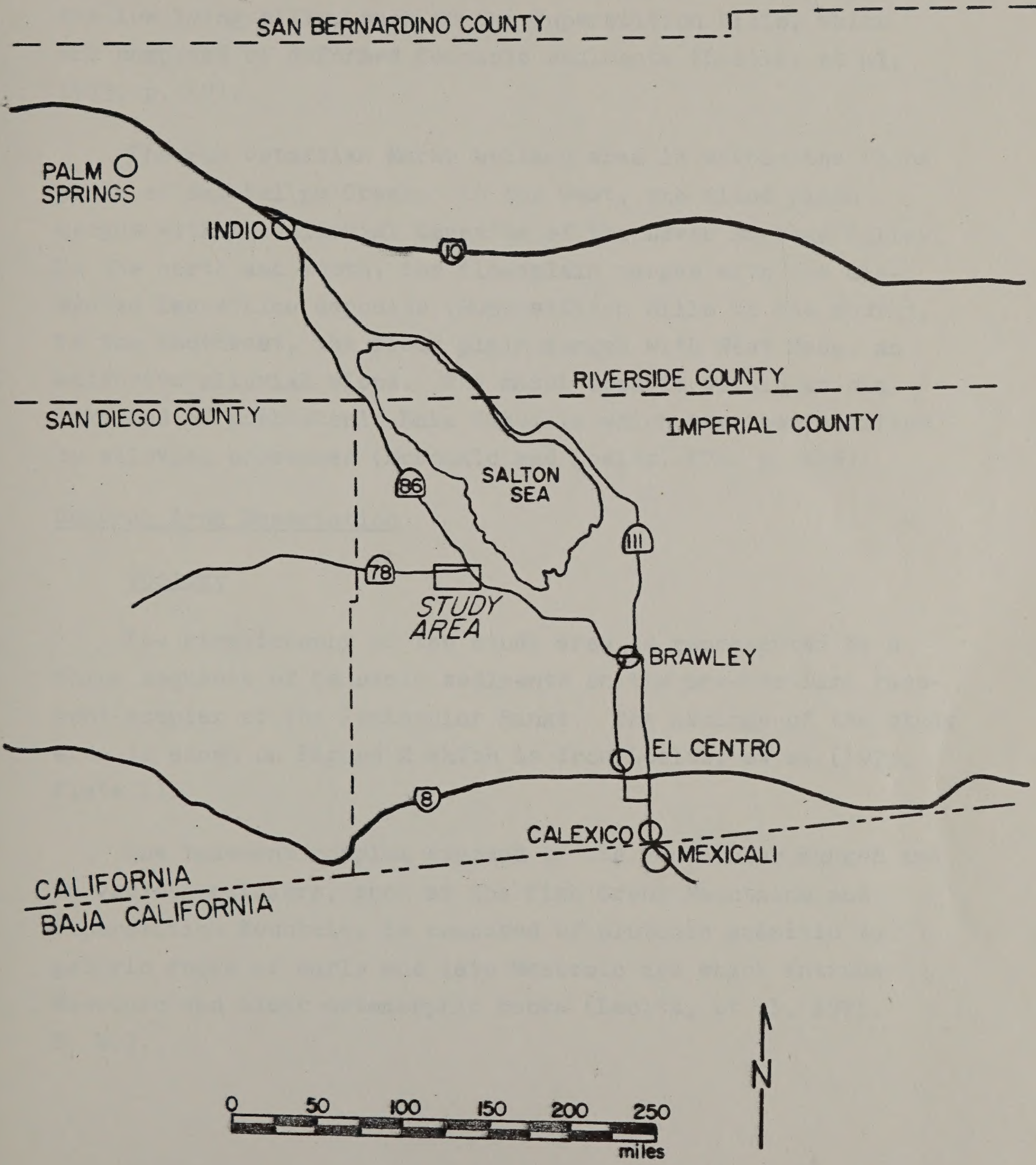
This report presents the work accomplished in the first phase of this study of the geohydrology of the lower San Felipe Creek drainage area. The tasks performed in this study included: (1) an inventory, synthesis and interpretation of available geohydrologic data; (2) identification and mapping of the areal distribution of surface water and measurements of flowing springs in the San Sebastian Marsh wetland area; (3) identification and description of ground water flow models to provide predictions of the impact of proposed pumping; (4) identification and discussion of the practical boundary conditions for use in such a model; and (5) recommendations for additional data needed to calibrate the model and to better define the geohydrology of the lower San Felipe Creek drainage area.

Geographical Context

The San Sebastian Marsh wetland area is in Imperial County near the Salton Sea and is located near the intersections of Highways 86 and 78 as shown on Figure 1. The nearest city is Westmorland, California, 15 miles to the southeast. Although the wetland area comprises only 11 sections in Township 12 South, Ranges 10 and 11 East (T12S/R10E, R11E), the entire lower San Felipe Creek drainage area which covers an area comprised of T11S/R7E, R8E, R10E and R11E; T12S/R7E, R8E, R9E, R10E and R11E; T13S/R9E, R10E and R11E; and T14S/R10E, must be included in a hydrogeologic study.

This area is composed of topographically complex alluvial surfaces between the Peninsular Range to the west and the central Imperial Valley to the east. The elevations of the alluvial surfaces range from 2000 feet at the foot of the Peninsular Range to -200 feet near the Salton Sea.

FIGURE 1
LOCATION MAP



Within the study area, the Fish Creek Mountains and Superstition Mountains are exposures of the pre-Tertiary basement complex of the main Peninsular Range (Loeltz, et al, 1975, p. K7). These outliers are rugged exposures as compared to the low lying hills, such as the Superstition Hills, which are composed of deformed Cenozoic sediments (Loeltz, et al, 1975, p. K7).

The San Sebastian Marsh wetland area is within the flood plain of San Felipe Creek. To the west, the flood plain merges with the alluvial deposits of the Lower Borrego Valley. To the north and south, the floodplain merges with the dissected lacustrine deposits (Superstition Hills to the south). To the southwest, the flood plain merges with West Mesa, an extensive alluvial slope. The marsh area is within an old lake bed of prehistoric Lake Cahuilla which has been modified by alluvial processes (McDonald and Loeltz, K76, p. 416).

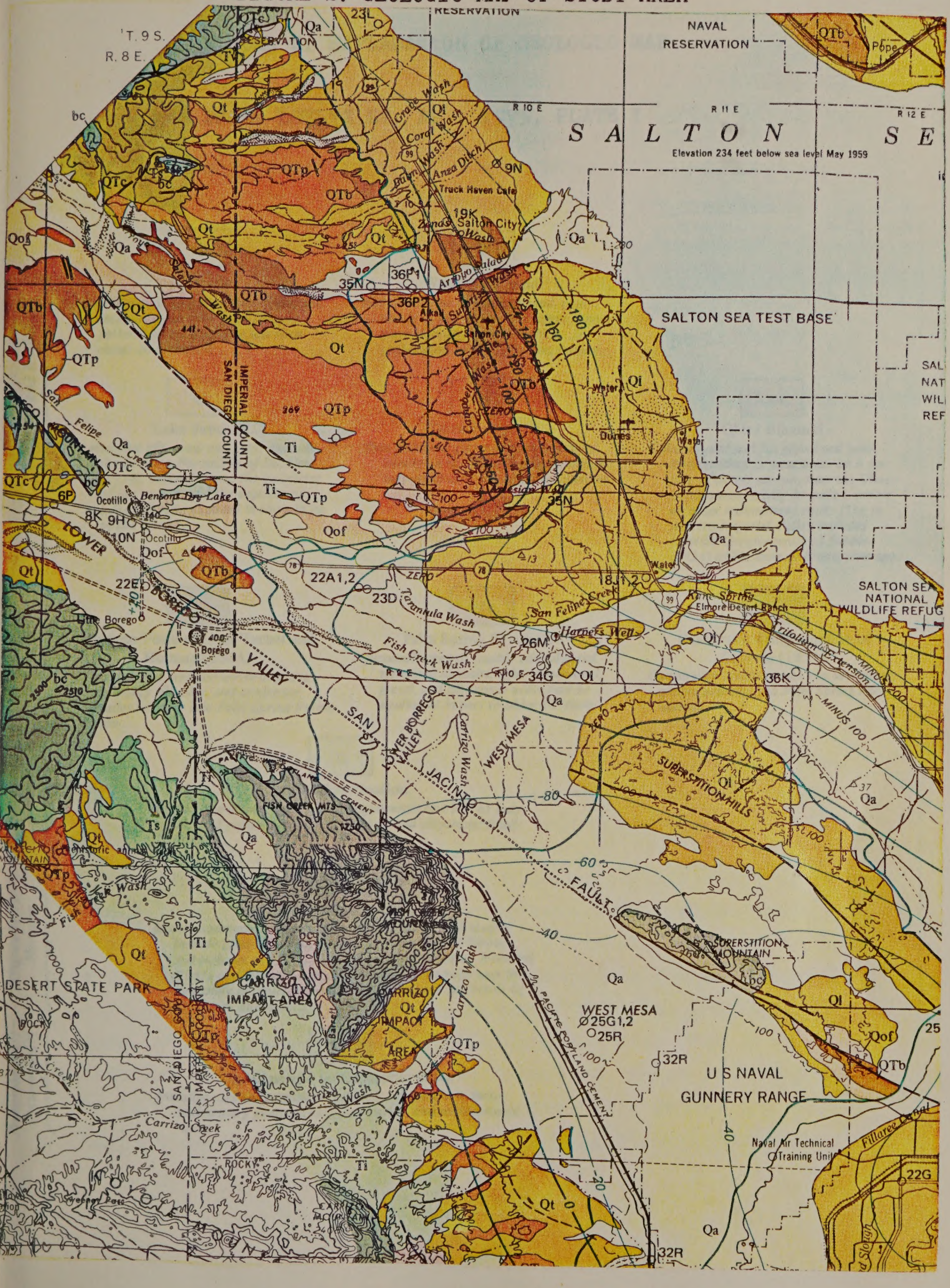
General Area Description

Geology

The stratigraphy of the study area is represented by a thick sequence of Cenozoic sediments on the pre-Tertiary basement complex of the Peninsular Range. The geology of the study area is shown on Figure 2 which is from Loeltz, et al (1975, Plate 1).

The basement complex exposed in the Peninsular Ranges and in various outliers, such as the Fish Creek Mountains and Superstition Mountain, is composed of plutonic granitic to gabbric rocks of early and late Mesozoic age which intrude Mesozoic and older metamorphic rocks (Leoltz, et al, 1975, P. K7).

FIGURE 2. GEOLOGIC MAP OF STUDY AREA



ADAPTED FROM: LOELTZ, ET. AL., 1975, PLATE I

FIGURE 2. EXPLANATION OF GEOLOGIC MAP

FROM: LOELTZ,ET. AL., 1975, PLATE I

Pleistocene and Holocene

Qa

Alluvium

Alluvial and deltaic sand, gravel, and silt. Includes some dune sand (stipple pattern) where generally less than about 10 feet thick

Qs

Windblown sand

Well-sorted fine to medium sand, commonly in high dunes and ridges, where more than about 10 feet thick. Includes Sand Hills (Algodones Dunes)

Ql

Lake deposits

Lacustrine silt, sand, and clay. Include the Brawley Formation of Dibblee (1954), exposed along the perimeter of the trough, and the deposits of Lake Cahuilla, exposed in the middle of the trough

Qt

Terrace deposits

Thin pediment gravel and sand, formed mostly on the Palm Spring Formation; may grade into fans of older alluvium

Qof

Older alluvium

Older alluvial and fan gravel and sand, distinguished in most areas by a surface of desert varnish; near the Chocolate Mountains may be only a veneer on older sedimentary rocks (Ts); in western Imperial Valley includes Ocotillo Conglomerate of Dibblee (1954) of Pliocene or Pleistocene age

Pliocene and Pleistocene

QTb

Borrego Formation of Tarbet and Holman (1944)

Lacustrine and brackish-water deposits; light-gray silt, clay, and sandstone; grades laterally into Palm Spring Formation

QTp

Palm Spring Formation

Unconsolidated to weakly consolidated terrestrial deposits; light-brown sand, gravel, and silt; upper units may be equivalent in part to older alluvium

QTc

Canebreak Conglomerate of Dibblee (1954)

Coarse silty conglomerate and sandstone; grades laterally into Palm Spring Formation

Miocene or Pliocene

Ti

Imperial Formation

Shallow marine deposits; basal conglomerate overlain by gray, tan, and yellow siltstone, sandstone, and claystone; fossiliferous

Oligocene(?) - Miocene

Ts

Sedimentary rocks

Mostly nonmarine coarse sedimentary rocks of several ages; include Split Mountain Formation (Miocene) of Tarbet and Holman (1944), and its proposed revisions by Woodard (1961) and Durham and Allison (1961); outcrops near the Chocolate Mountains are of Oligocene(?) age (prebasalt of Chocolate Mountains)

Precambrian(?) - Cretaceous(?)

bc

Igneous and metamorphic rocks

Intrusive rocks of granitic to gabbroic composition, metasedimentary gneiss, schist, and marble, and metavolcanic rocks

Overlying the basement is a thick sequence of primarily non-marine sediments ranging in age from Eocene to Holocene. The following descriptions of the Cenozoic units are from reports by Loeltz, Irelan, Robison and Olmstead (1975, p.K9-11) and Moyle (1968, p. 7-9).

Tertiary deposits include the Eocene Maniobra Formation, a marine conglomerate and breccia; the Miocene Alverson Andesite Lava; the Miocene Split Mountain Formation, a non-marine breccia; the Miocene Fish Creek Gypsum, a marine arenite; and the Miocene to Pliocene Imperial Formation; a marine siltstone-claystone-sandstone with a basal conglomerate.

Overlying the Imperial Formation is a sequence of Pliocene to Pleistocene sediments: the Canebrake Conglomerate, the Palm Spring Formation and the Borrego Formation. The relationships of all the sedimentary units above the Imperial Formation are shown on Figure 3, adapted from Loeltz, et al (1975, Figure 5, p. K9). These three units represent a gradation of coarse fan deposits to fine-grained lake deposits; the Canebrake Conglomerate is a cobble-pebble conglomerate, the Palm Spring Formation is composed of fluvial and deltaic sandstone, siltstone and claystone and the Borrego Formation is composed of fine-grained lacustrine siltstone and claystone.

Overlying this sequence of Pliocene to Pleistocene sediments is a younger sequence of coarse-to-fine-grained sediments of Pleistocene age. The Borrego Formation is immediately overlain by older alluvium composed of coarse-grained, moderately consolidated and slightly cemented alluvial gravel and sand, which includes the Ocotillo Conglomerate. The older alluvium grades into the Brawley Formation, which is composed of lacustrine silt and clay. In places, thin gravel and sand terrace deposits directly overlie the Palm Springs Formation.

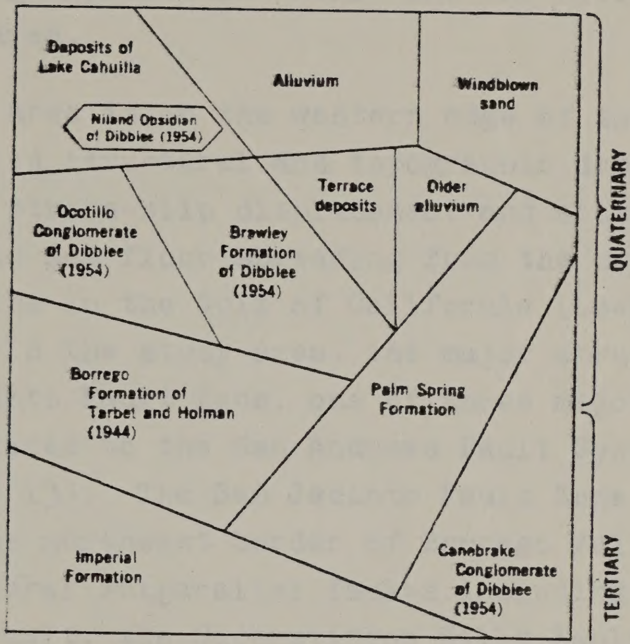

Deposits of Lake Cahuilla
Alluvium
Windblown sand
Niland Obsidian of Dibblee (1954)
Terrace deposits
Older alluvium
Ocotillo Conglomerate of Dibblee (1954)
Brawley Formation of Dibblee (1954)
Borrego Formation of Tarbet and Holman (1944)
Palm Spring Formation
Imperial Formation
Canebrake Conglomerate of Dibblee (1954)
QUATERNARY
TERTIARY

FIGURE 3.
Stratigraphic Relationships Of Upper Tertiary And Quaternary Units In The Study Area

Within the study area, the youngest surficial units are Holocene alluvium, which is composed of unconsolidated alluvial and fluvial sand, gravel and silt, and Holocene lake deposits of Lake Cahuilla, which are composed of lacustrine silt, sand and clay. The Quaternary lake sediments shown on Figure 2 include the Brawley Formation which is exposed in the low flanking Superstition Hills and the hills north of the marsh wetland area.

The study area is on the western edge of the Salton Trough, a sediment-filled structural and topographic depression formed as a result of strike-slip displacement and cross-strike separation related to sea floor spreading from the crest of the East Pacific Rise in the Gulf of California (Loeltz, et al, 1975, p. K7). In the study area, the major structural feature is the San Jacinto Fault Zone, one of three major right lateral fault zones related to the San Andreas Fault System (Dutcher, et al, 1972, p. 13). The San Jacinto Fault Zone trends southeast forming the northeast border of Borrego Valley and then splits into several subparallel faults including the Superstition Mountain Fault, the Superstition Hills Fault and the Imperial Fault (Loeltz, et al, 1975, p. K7 and Dutcher, et al, 1972, p. 13). Faulting in the study area is shown on Figure 4. As shown, the trend of the San Felipe Hills Fault crosses through the San Sebastian Marsh wetland area, aligning closely to the Superstition Hills Fault. Its strike through the wetland area is close to the springs on San Felipe Creek and Fish Creek Wash and therefore the faulting is mostlike related to the occurrence of these springs. If faulting is present through the younger sediments, it may create a partial barrier to the eastward movement of ground water.

Hydrology

The study area is drained by San Felipe Creek and its major tributaries, Fish Creek Wash and Carrizo Wash. The

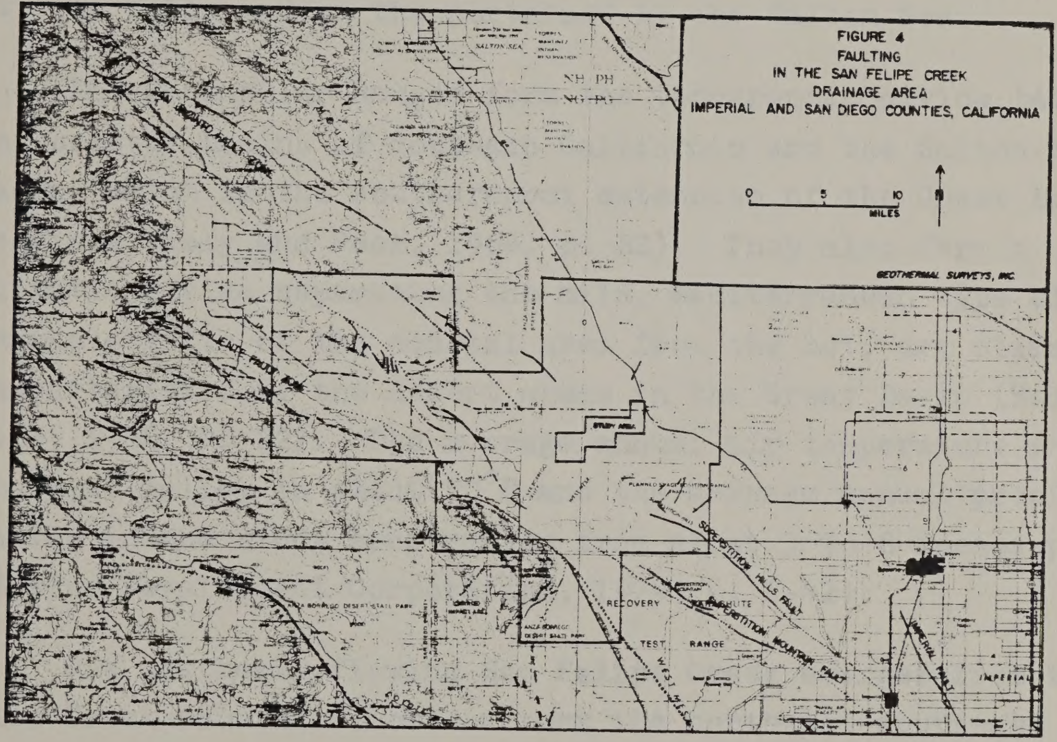


FIGURE 4
FAULTING
IN THE SAN FELIPE CREEK
DRAINAGE AREA
IMPERIAL AND SAN DIEGO COUNTIES, CALIFORNIA

confluence of these three drainages is within the boundaries of the San Sebastian Marsh wetland area. The surface drainage area boundary for the San Felipe Creek - Fish Creek Wash - Carrizo Wash drainage system is outlined on Figures 5, 6, and 7 which show the precipitation, evapotranspiration and runoff over the drainage area. The surface drainage area of the San Felipe - Fish Creek - Carrizo Wash drainage system, approximately one million acres, heads in the Peninsular Range on the west and is bounded on the north by the Santa Rosa Mountains, on the southeast by Superstition Mountain and the Superstition Hills and on the northeast by the Salton Sea.

The Peninsular Ranges form the topographic divide between the coastal basins of Southern California and the Salton Sea Basin, which is the southernmost extension of the Great Basin Province (Hely and Peck, 1964, p. B2). They also form a climatic divide separating the mild, Mediterranean type climate characteristic of the coastal area from the hot, dry climate characteristic of the desert areas in the Great Basin (Hely and Peck, 1964, P. B2). The average annual air temperature in the Imperial Valley is about 70°F and the average annual precipitation in the study area ranges from about 3 to 8 inches per year (System Development Corporation, 1979, p. I-42).

The northerly-flowing San Felipe Creek emerges from the Fish Creek Mountains, cuts across the northwest-southeast trending Borrego Mountain and then makes a sharp bend to the southwest at the confluence with the surface drainage from Borrego Valley to the west. It is possible that the San Felipe Creek drainage was captured by a drainage flowing to the southeast, north of Borrego within the San Jacinto fault zone. A tributary to this drainage may have cut through Borrego Mountain along a southwest trending fault (other southwest trending faults in Borrego Mountain are shown on Figures 2 and 4)

and captured the San Felipe Creek surface drainage. The original San Felipe Creek drainage would thus have been to the southeast towards Ocotillo Wells south of Borrego Mountain.

Within the study area, the San Felipe-Fish Creek-Carrizo drainage system is characterized by ephemeral stream courses. The mountainous headwaters of the streams support perennial flow. When the stream courses reach the alluvial basin, infiltration to the ground water body causes a decrease in flow until the drainages become ephemeral, with the water table far below the ground surface (Hely and Peck, 1964, p. B11). Because of this change from perennial to ephemeral conditions, a large percentage of the recharge to the alluvial ground water basin should occur from infiltration of surface flow along the more permeable fringes of the basin. Within the study area, except within the San Sebastian Marsh wetland area, the streams flow only in direct response to precipitation.

Within the San Sebastian Marsh wetland area near the confluences of Fish Creek and Carrizo Washes with San Felipe Creek springs provide perennial surface flow to San Felipe Creek, for a downstream stretch of almost four miles. This perennial flow provides the habitat for the wildlife in the wetland area.

The sequence of Quaternary sediments described previously form the principal ground water reservoir. The coarser sediments in the western part of the study area such as the Ocotillo Conglomerate, the older alluvium and the Holocene alluvium can be expected to provide more production than the finer-grained sediments nearer the Salton Sea, such as the Brawley Formation and the Holocene lake sediments. However, the lacustrine sediments can be expected to store and transmit

some water. Because of their large areal distribution they are an important part of the ground water basin.

METHODOLOGY AND SCOPE

Available data has been collected and has been used to obtain the hydrologic parameters necessary to develop a baseline evaluation of the geohydrology of the lower San Felipe Creek drainage area under present conditions.

A field investigation was undertaken to determine location and extent of surface waters within the San Sebastian Marsh area.

The characteristics of different types of digital ground water models were examined in detail to determine their suitability for application to the San Sebastian wetlands area.

Geohydrology

Well Data Assessment

An assessment of the ground water basin and determination of the characteristics of the aquifer(s) was made by canvassing available well data. Published references including Bradshaw and Donnan (1952), Burnham (1954), Moyle (1968), Werner and Olson (1970), Loeltz, et al (1975) and Hardt and French (1976) provided most of the data. Unpublished information from the California Department of Water Resources, Coachella Valley Pump and Supply, Inc., and a study of Ranch Oasis done by Koebig and Koebig (1970) has also been used. The following organizations were also contacted to gather available information:

- State of California, Department of Water Resources, Southern District Office, Los Angeles, California

- U.S. Geological Survey, Water Resources Division, Lower Colorado River Project, Yuma, Arizona
- State of California, Regional Water Quality Control Board, Colorado River Basin Region, Palm Desert, California
- County of Imperial, Engineering Department, El Centro, California
- Imperial Irrigation District, Water Engineering Department, Imperial, California
- U.S. Department of Agriculture, Soil Conservation Service, El Centro, California
- Coachella Valley Pump and Supply, Inc., Indio, California

The types of well data used in this study consist of: (1) well locations and elevations, (2) lithologic logs, (3) well design information, (4) well test measurements, (5) water level measurements, (6) geophysical logs, and (7) water quality analyses.

The lithologic logs were examined to identify the thichness and lateral extent of distinct aquifer zones. Stratigraphic intervals of coarser grain size were selected as probable aquifers and an attempt was made to correlate these intervals between wells. It is apparent that more than one aquifer is present in the vicinity of the Ranch Oasis Wells (T12S R9E, Sections 22, 23, 25 and 26). Up valley in the drainage area the deeper, confined aquifer(s) become unconfined and open to recharge. The lithologic logs of the wells in the western part of the drainage area were used to determine where recharge is occurring to all the aquifers. The lithologic material which comprises the aquifers has also been used to quantify the specific yield.

Production tests have been made on some of the wells in the study area. The records of testing of the Ranch Oasis Wells have been especially well documented. The productivity of the wells has been evaluated with respect to the interval perforated in the well to quantify the productivity of different aquifers.

Water level measurements are available for most of the wells in the study area. These data have been used to determine movement of the ground water. When correlated with the depth of the well and the interval perforated, the water levels were used to identify different aquifers. Water level records have also been used to estimate water level decline.

Geophysical studies in the Imperial Valley have been made primarily in the geothermal areas southeast of the Salton Sea. No reference was found to any surface geophysical studies in the lower San Felipe Creek area. Some of the Ranch Oasis wells and two wells drilled by the U.S. Geological Survey, LCRP19 and LCRP 8 have had downhole geophysical logs made. These data were used in aquifer identification.

Results of water quality analyses have been included in this report. This study has not made an in-depth evaluation of water quality except to aid aquifer identification. Future evaluation of the impact of ground water development in the study area must consider water quality changes. Therefore available water quality data have been included in this report.

Aquifer Recharge, Discharge and Storage

In order to determine aquifer recharge, discharge, and storage, an average annual water budget was made. To assess the water budget, the inflows are balanced against outflows with the residual equal to change in ground water storage.

The major inflow to the study area is precipitation which falls on the surface drainage area of the San Felipe - Fish Creek - Carrizo drainage system. Hely and Peck (1964, p. B2-B6) made a determination of average annual precipitation over the entire Salton Sea Basin drainage area and presented the results as an isohyetal map in their report. Figure 5, the average annual precipitation over the San Felipe Creek drainage area was adapted from Plate 3 of this report. The total volume of average annual precipitation was determined by multiplying the surface area within the San Felipe Creek drainage boundary by the amount of precipitation. This was done by dividing the drainage basin into subareas of equal average annual precipitation multiplying the surface area of each subarea by its value of precipitation and summing all the subareas.

Most of the precipitation total will be lost to evapotranspiration, which in a hot, arid climate equals a high percentage of the precipitation. Hely and Peck (1964, p. B15-B16) made a determination of average annual actual evapotranspiration over the entire Salton Sea Basin drainage area and presented the results on a contour map showing lines of equal evapotranspiration. Figure 6, the average annual actual evapotranspiration over the San Felipe Creek drainage area was adapted from Plate 7 of Hely and Peck (1964). The volume of water in the budget which is lost to evapotranspiration was calculated by dividing the drainage basin into subareas of equal evapotranspiration, multiplying the surface area of each subarea by its value of evapotranspiration and summing all the subareas.

The calculated volume of average annual actual evapotranspiration was subtracted from the calculated volume of average annual precipitation. The residual is the amount of water available for surface flow and infiltration to the ground water.

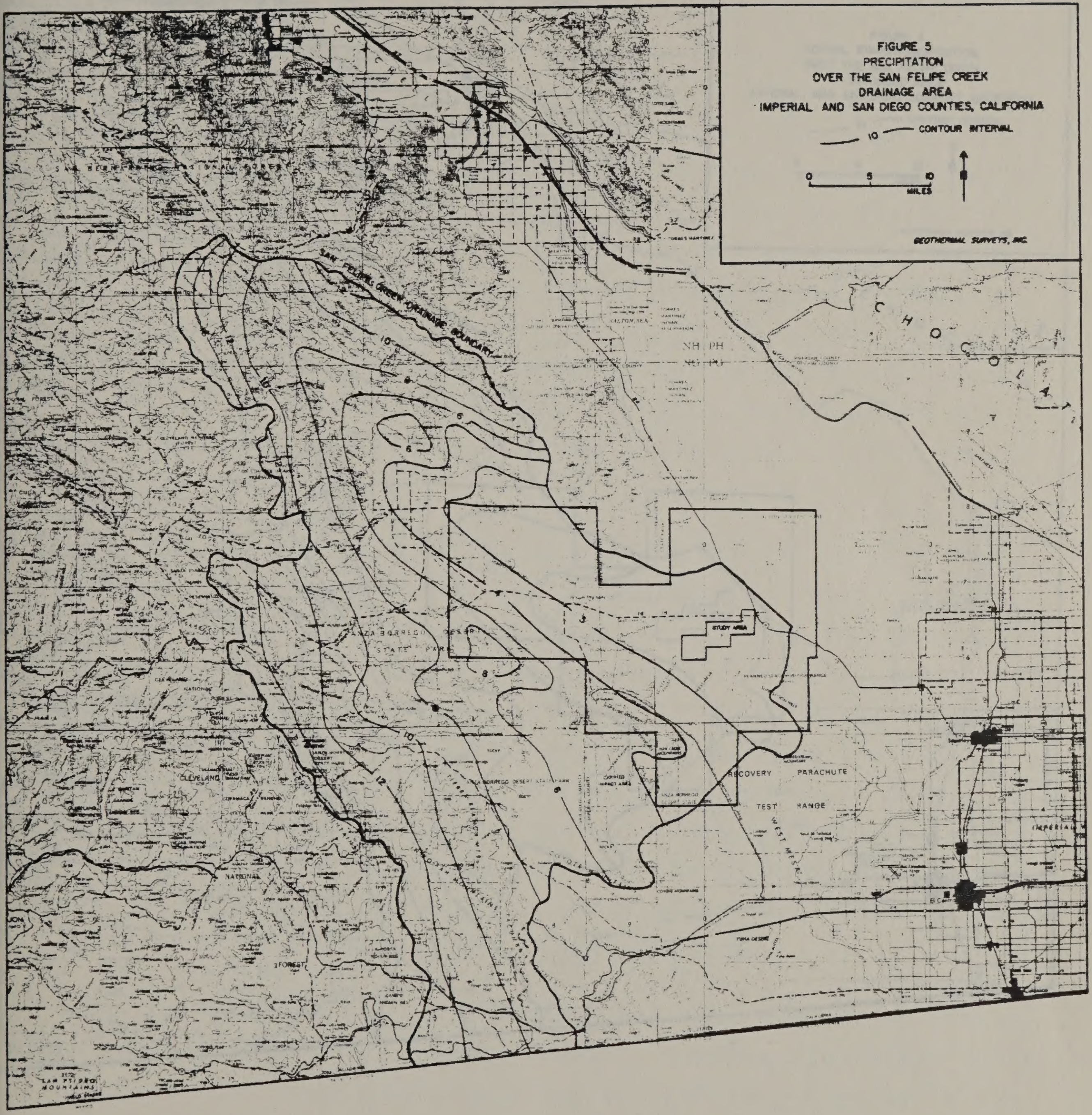


FIGURE 5
PRECIPITATION
OVER THE SAN FELIPE CREEK
DRAINAGE AREA
IMPERIAL AND SAN DIEGO COUNTIES, CALIFORNIA

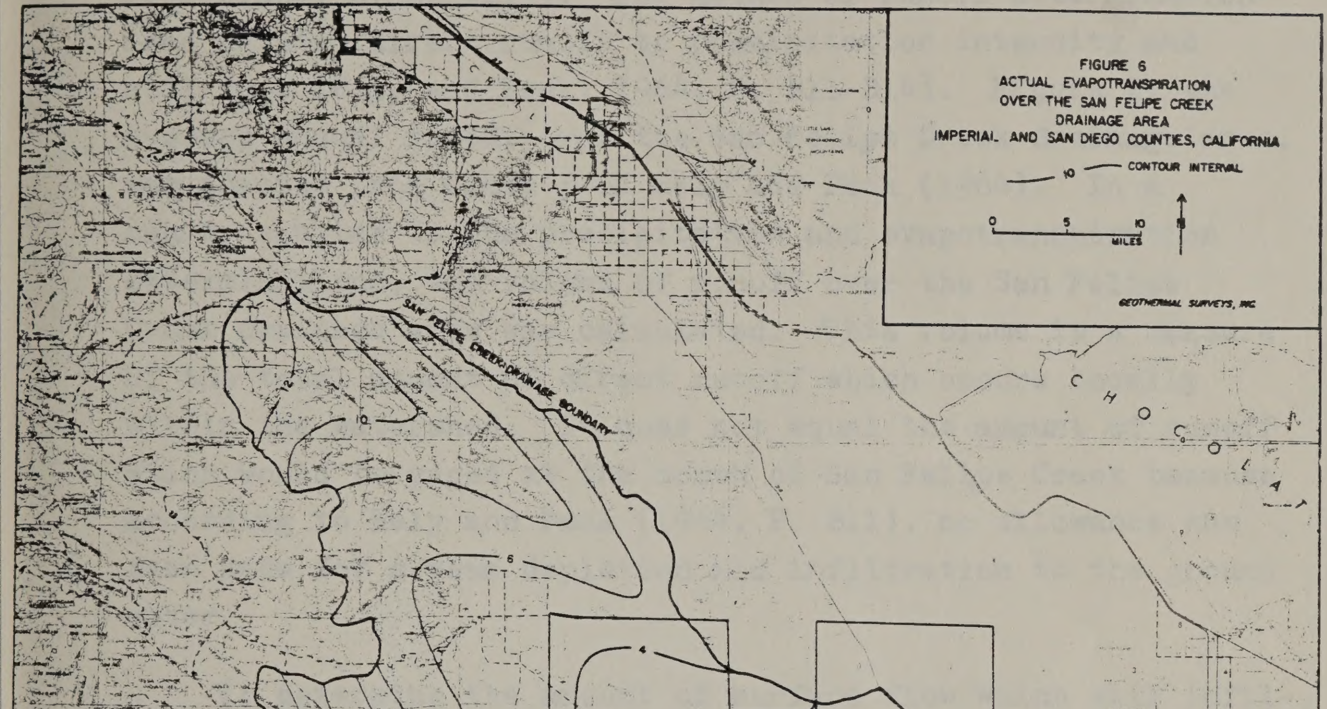


FIGURE 6
ACTUAL EVAPOTRANSPIRATION
OVER THE SAN FELIPE CREEK
DRAINAGE AREA
IMPERIAL AND SAN DIEGO COUNTIES, CALIFORNIA

The amount of runoff which will occur over the entire San Felipe Creek drainage area was determined by Hely and Peck (1964, p. B11-B15). The method of runoff determination used relates direct runoff to precipitation intensity and soil type (Hely and Peck, 1964, P. B11-B14). Figure 7, the average annual runoff over the San Felipe Creek drainage area, was adapted from Plate 5 of Hely and Peck (1964). In a manner similar to the precipitation and evapotranspiration determinations, the volume of runoff over the San Felipe Creek drainage area was calculated. This volume is a measure of the total amount of direct runoff which occurs locally within the watershed. It does not equal the amount of runoff which would be gaged at the mouth of San Felipe Creek because according to Hely and Peck (1964, P. B11), no allowance has been made for stream depletion and infiltration to the ground water.

To determine the amount of surface flow which will infiltrate to the ground water, the average annual runoff on San Felipe Creek, which was measured at a gage near the intersection of Highways 86 and 78, was subtracted from the calculated volume of runoff determined over the entire drainage area of San Felipe Creek. The amount of infiltration to the ground water should comprise nearly all of the recharge to the aquifers in the study area. Most of this infiltration is expected to occur along the edges of the alluvial basin where the streams enter the basin from the mountains. This is the area of major recharge for all the aquifers.

Recharge to the uppermost aquifer will also occur due to direct infiltration of precipitation, surface flow after storms, surface flow from springs and applied irrigation water in the central part of the basin near and within the San Sebastian Marsh wetland area. Since precipitation is small in the central part of the basin and since relatively little agricultural

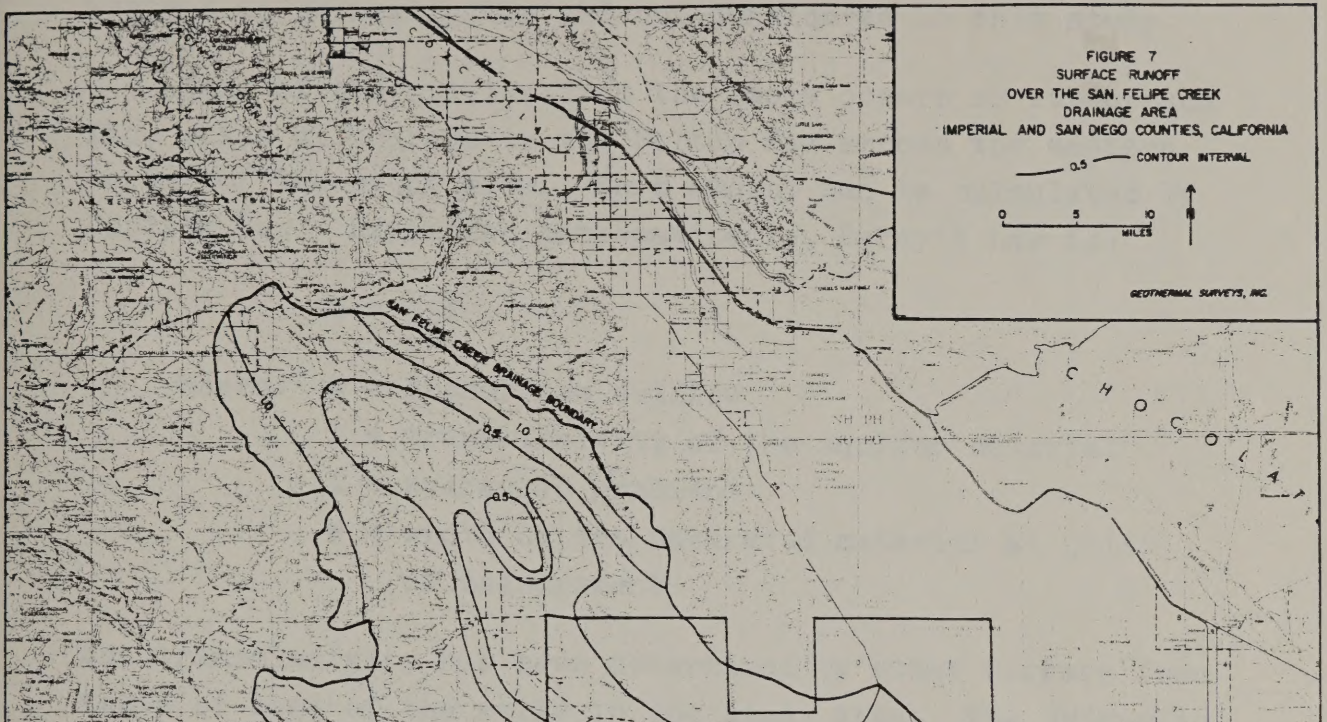


FIGURE 7
SURFACE RUNOFF
OVER THE SAN. FELIPE CREEK
DRAINAGE AREA
IMPERIAL AND SAN DIEGO COUNTIES, CALIFORNIA

development occurs at present, this amount of recharge is assumed to be negligible and not considered in this study.

Most of the outflow from the basin occurs as subsurface flow which discharges to the Salton Sea across the eastern border of the study area. This amount can be calculated by Darcy's Law. Expressed mathematically, Darcy's Law is:

$$Q = TiW$$

Where: Q = subsurface outflow
T = transmissivity of the aquifer material
i = hydraulic gradient
W = width of the saturated material at point of measurement

The transmissivity has been determined by other workers from tests of some of the wells in the study area. The hydraulic gradient has been determined by the slope in the water surface between wells along the direction of major flow.

Under long term average conditions with no change in ground water storage, the value of subsurface outflow should equal the amount of recharge which reaches the ground water body.

The amount of ground water in storage within the study area was determined by the specific yield method. The average thickness of aquifer material is multiplied by the surface area of the study area within the considered boundaries of the main ground water basin. This volume is then multiplied by a representative specific yield for the aquifer material to give the volume of ground water in storage.

Surface Hydrology

A field investigation of the surface water in the San Sebastian Marsh wetland area has been made on two occasions

approximately three months apart. During both on-site investigations, the areal distribution of standing and flowing surface water was mapped. The stream bottoms were examined from the sites of the first appearance of surface water near the mapped springs to the downstream point where flowing surface water disappeared. Surface flow measurements were made on Carrizo Wash and San Felipe Creek at the confluence of these two drainages.

An investigation of the Harper's well site was also made. Surface water at this site is supported by flow from a well casing in the stream bottom. The amount of flow from the casing was measured by bailing the water out of the casing until the water level was lowered to a specified point and then measuring the time required for the water level to recover to the top of the casing.

Identification of Ground Water Models

Mathematical ground water models provide a simplified description of aquifer behavior. Such models are useful as an aid in obtaining aquifer characteristics and may be used as a predictive tool to simulate aquifer response to imposed stresses.

The continuous function of ground water flow is described by a partial differential equation which relates change in hydraulic gradient to change in flow over time. The equation is based on conservation of mass expressed as a water budget and conservation of momentum expressed as Darcy's Law.

The two-dimensional flow of confined ground water can be expressed by the following partial differential equation (Trescott, 1975, p. 4):

$$\frac{\partial}{\partial x}\left(T_{xx}\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial x}\left(T_{xy}\frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial y}\left(T_{yx}\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(T_{yy}\frac{\partial h}{\partial y}\right) + W(x,y,t) = S\frac{\partial h}{\partial t}$$

Where: T = components of the transmissivity
h = head
S = storage coefficient
W = source or sink term
x,y = cartesian coordinates
t = time

In this equation the terms on the left side are the difference in flow in and out of the control volume and the term on the right side is the change in storage rate (Mercer and Faust, 1980b, p. 214). The source term (W) includes well discharge, induced infiltration from streams, leakage from confining beds, recharge from precipitation, and evapotranspiration (Trescott, et al, 1976, p. 4). If the aquifer under consideration is unconfined, then the transmissivity terms are changed to permeability times aquifer thickness (Kb) to account for the parameter changing as the water level is lowered (Trescott, 1975, p. 4).

With a multiple layer case such as the San Sebastian Marsh area, the confining layer can be treated in a number of ways. If storage in the confining layer is insignificant and horizontal flow is significant, then the confining layer is treated as a layer of nodes. If storage in the confining layer is significant, then more than one layer will be necessary to simulate the confining layer. If storage and horizontal flow in the confining bed are insignificant, then vertical flow through the confining layer can be treated by incorporating a vertical component of permeability with the adjacent aquifers

(Trescott, 1975, p. 28). The term listed below is added to the left side of the previous equation in this case (Mallory, 1979, p. 2):

$$\frac{K'}{b'} (h-h')$$

Where: K' = vertical permeability of the confining layer
b' = thickness of confining layer
(h-h') = difference in head between the adjacent aquifers

For larger areas with irregular boundaries and varying aquifer characteristics, the area is subdivided into subareas. The continuous partial differential for each subarea is approximated by an algebraic equation in which the variables are defined at specific points. The resulting set of N equations in N unknowns, including boundary conditions and initial values, can then be simultaneously solved using matrix methods on a computer.

The procedure for working with a ground water model includes:

1. choosing the technique,
2. construction of the model,
3. data collection,
4. model calibration,
5. model verification,
6. prediction.

Choosing the Model

The choice of model depends on such factors as the objective of the study, complexity of the study area, degree of accuracy required, the amount of data available, the amount of computer storage and time available, and the preference of the modeler.

The two basic approaches are the finite-difference method and the finite-element method. The finite-difference method approximates the partial differential equations with a difference approach and the finite-element method approximates the partial differential equations with an integral approach.

With the finite-difference method, three types of grid can be used. Two types utilize a rectangular grid with either mesh-centered or block-centered node points. The node point is the position within each subarea which represents the unknown values over the entire subarea. In mesh-centered grids, the node points are at the intersection of the grid lines and in block-centered grids the node points are centered between grid lines. According to Faust and Mercer (1980, p. 396), the mesh-centered grid is more convenient when considering constant head boundary conditions and the block-centered grid is more convenient when considering constant flux boundary conditions. The coordinate axes for the grid should be oriented so that they are parallel to the direction of maximum ground water flow. The third type of grid is an arbitrary grid where node points are selected and polygons constructed around them according to the Thiessen method (Tyson and Weber, 1964). The polyganal grid requires more careful construction than the rectangular grids and requires more input data into the model. However, the polyganal grid allows greater geometric flexibility on the areal shape of the aquifer and allows greater concentration of nodes in areas with more data.

The finite-element method approximates the dependent variables in terms of interpolation functions which are defined over a finite number of subdomains by low-order polynomials (Faust and Mercer, 1980, p. 398). The region is divided into subregions called elements whose shapes are determined by sets of node points. The elements can have various shapes so that

regions of complex geometry are easily accomodated. The irregular spacing of node points used in this method results in the ability to use fewer nodes than the finite-difference mesh grids.

Faust and Mercer (1980, p. 404-405) made the following points in comparing the finite-difference and finite-element methods: (1) the theoretical basis of the finite-difference method is straightforward and easy to understand and the theoretical basis of the finite-element method is advanced and more abstract; (2) the finite-difference method is relatively easy to program and the finite-element method is relatively difficult to program; (3) the finite-difference mesh grid is simple to design with easy grid parameter input, the finite-difference polyganal grid is more difficult to design with more grid parameters to input, and the finite-element grid design and parameter input are difficult and prone to errors which are hard to find; (4) the finite-difference mesh grid can not approximate complex boundary geometry and the finite-difference polyganal grid and finite-element grid can approximate complex boundary geometry; (5) the finite-difference method has lower order approximations and may have lower accuracy and the finite-element method has higher order approximations and may have higher accuracy; and (6) the finite-difference method can not evaluate cross-product terms and thus can have grid orientation effects (different solutions based on grid orientation) and the finite-element method can easily handle cross-product term, tensor parameters.

With both methods the set of equations for all the nodes are combined to form a matrix equation with N equations and N unknowns where N is the number of nodes. The matrix equation can be solved by one of two basic techniques, the direct method

and the iterative method (Faust and Mercer, 1980, p. 399). The direct method performs the sequence of operations once to provide an exact solution. With the iterative method, an initial guess is made for the dependent variable and then an iterative process of successive approximations is made until an error criterion is attained. The main disadvantage to the direct method is that it requires more computer storage and computer time while the iterative method is more efficient for computer use.

Constructing the Model

The initial step in subdividing the study area is to select the boundaries. These boundaries are either physical or convenient. The boundary conditions include the geometry of the boundary and the values of dependent variables perpendicular to the boundary (Mercer and Faust, 1980b, p. 218). Types of boundary conditions include constant head, no flow (impermeable), constant flux or variable dependent flux. If a boundary of convenience is chosen it should be far enough away from the area of aquifer to be simulated, that no effect on the area of interest can occur due to activity at or outside the boundary.

Once the boundaries have been selected, the area within the boundaries is subdivided with a grid network. The size of the gridded subareas depends on the existing data and the required detail desired in the predictions. The aquifer parameters and head are specified for each node and are considered constant over the subarea.

When designing the grid network, certain principles to observe are (Trescott, et al, 1976, p. 31):

1. nodes in subareas which contain pumping wells should be located near the physical location of the well or the center of the well field,
2. boundaries should be located accurately,
3. the grid spacing should be designed so that more intensively placed subareas cover physical areas where large differences in transmissivity or hydraulic head are anticipated,
4. axes of the grid should be oriented with the major direction of anisotrapy.

Data Collection:

Input data needed are:

1. estimates of transmissivity and storage coefficient for each node,
2. thickness of the aquifer at each node,
3. the water budget for each node,
4. initial values for hydraulic head at each node,
5. boundary values for constant head and constant flux nodes.

Model Calibration

The model is first run to simulate steady state flow with no change in storage. This is done to assure that the program is running correctly, to refine the estimates for the aquifer parameters and to test the accuracy of the boundary conditions.

Verification

After calibration is completed, a set of historic data is used to simulate changes in hydraulic head at each node. The verification period will often depend upon the period of historic data available. Differences between computed and actual heads may necessitate modification of the input parameters. When the model simulates historic water level data to the degree of accuracy desired, the model is said to be verified.

Prediction

Once verified the model can be used to simulate response in water levels throughout the aquifer to imposed stresses. The period of prediction should not exceed twice the period of verification (Mercer and Faust, 1980, p. 115). Changing field conditions will make predictions unreliable unless the model is adapted to those conditions.

Identification of Additional Data Requirements

Additional data needed for future geohydrologic study of the San Sebastian Marsh wetland area and the entire lower San Felipe Creek drainage area include input data needed for a model and data needed to better understand the geohydrology of the area.

Each node in the model grid needs the following input data: aquifer parameters, nodal dimensions, historic water levels for verification, and aquifer recharge or discharge. The boundary conditions for the boundaries also need to be specified. The study is further complicated by the presence of at least two aquifers separated by a confining layer. Aquifer parameters necessary for input for each aquifer are transmissivity, storage coefficient and saturated thickness. The

thickness, and vertical permeability and ability for storage for the confining layer are also needed. Records of well pumpage, precipitation and streamflow are needed to evaluate aquifer recharge and discharge. Boundary conditions will be an important consideration. The areal aquifer size for the study area is very large and most of the boundaries are not well known with available data.

Additional future data on the surface water in the San Sebastian Marsh will be needed to evaluate the fluctuation in areal distribution of surface water seasonally and from year to year.

Much of the study area has very little or no well information and the movement of ground water throughout the entire basin is not completely understood. The depth to the base of the aquifers and the number of discrete confined aquifers are not known at this time. Also the effect of faulting on the movement of ground water in the marsh area needs further study.

RESULTS

Geohydrology

The discussion of the geohydrologic results of this study, more specifically the lithology, well production tests, geophysical measurements, and water level measurements are based on well data collected from 108 wells in the study area. The location of the wells are shown on Figure 8. The well numbering system used in this report is that used by the U.S. Geological Survey and is shown in Appendix 1. Well information is presented in Appendices 2, 3, 4 and 5.

Lithology

The subsurface lithology of the ground water basin in the study area has been evaluated by studying driller's logs of 29 wells which are presented in Appendix 4. Of the 29 wells which have lithologic logs, 17 wells are in the western portion of the study area where the major recharge to the aquifers occurs (T11S/R7E and T12S/R8E). Eight of the wells are in the Ranch Oasis Area west of the San Sebastian Marsh (T12S/R9E - Sections 22, 23, 25 and 26). Of the remaining 4 wells, two of the wells are between the San Sebastian Marsh and the Salton Sea (T12S/R11E - 18J1 and 36K1), one of the wells is north of the marsh in the Quaternary lacustrine sediments (T11S/R10E - 35N1) and the fourth well is south of the marsh in the West Mesa area (T14S/R11E - 32R1).

The lithology of the subsurface material in the Lower Borrego Valley which comprises the western part of the study area, and forms the recharge area for the aquifers is predominantly coarse grained material, sand and gravel. The lithologic logs of the wells in T12S/R8E show 80-95% sand and gravel and 5-20% clay and silt. Since no thick clay layers are indicated in the driller's logs, it appears from the lithologic evidence that the aquifer penetrated by these wells is unconfined. It should be noted, however, that all of the wells except one are less than 325 feet deep and granitic basement was not noted on any log. Therefore a deeper confined aquifer may be present in the recharge area. The predominance of coarser material in the wells in the Lower Borrego Valley should allow sufficient infiltration and recharge for the deeper, confined aquifers in the marsh area.

The lithology of the subsurface material in the area in and around the San Sebastian Marsh is shown by the logs of

the Ranch Oasis wells and the U.S. Geological Survey wells at the eastern border of the marsh. Alternating layers of clay and sand were shown in the logs. The stratigraphic relationships of these wells is shown on Figure 9. The wells range in depth from 445 to 1250 feet. All of the well logs show a surface layer of sand to a depth of about 120 feet, ranging from 75 to 180 feet. This layer most likely represents the upper, unconfined aquifer in the marsh.

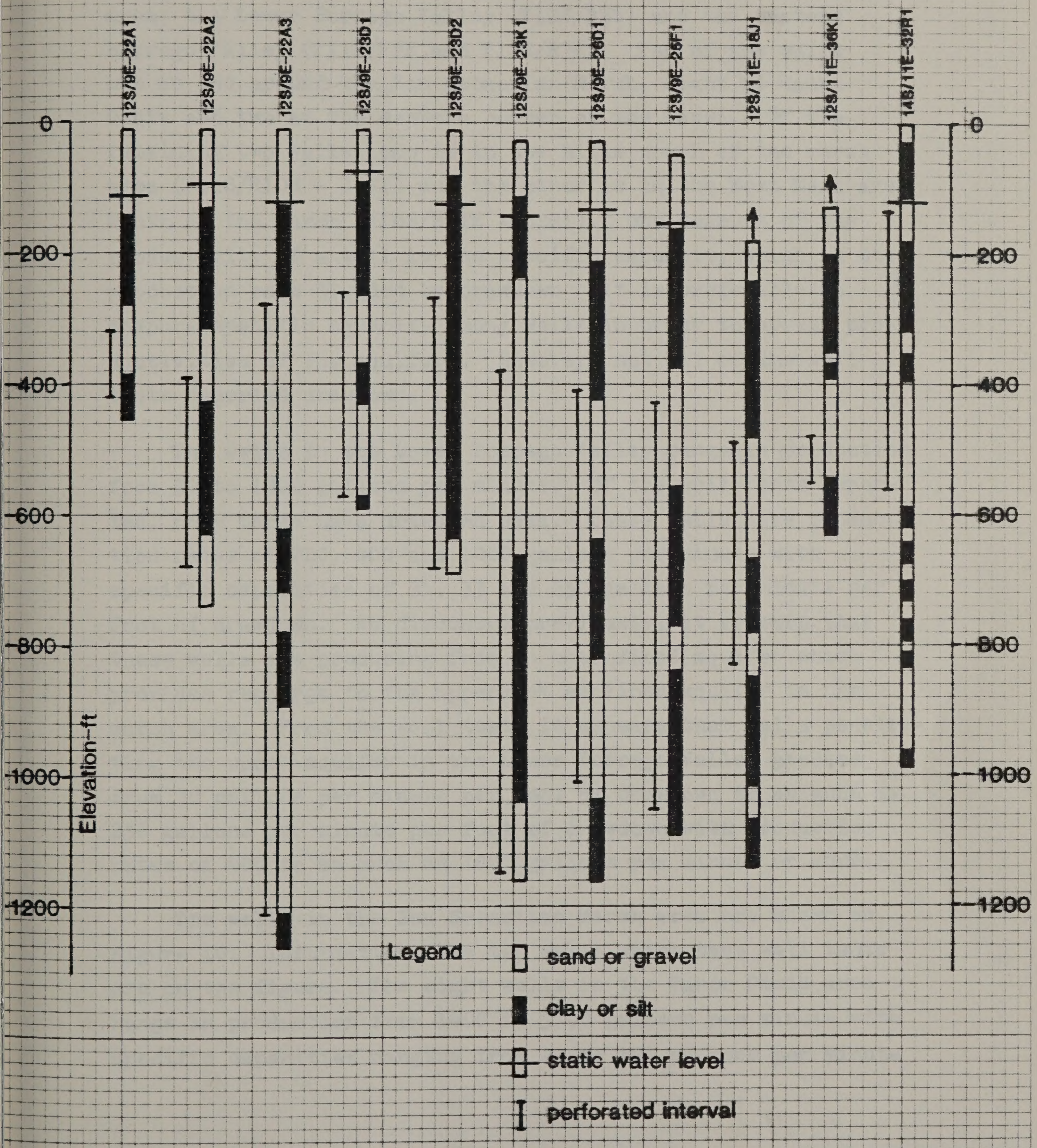
Beneath this surficial layer is a thick layer mainly of clay. Its thickness averages about 200 feet and extends to a depth of about 300 feet. This clay unit seems sufficiently thick and pervasive enough to form a confining layer for a deeper aquifer(s). Below the clay layer is a layer of sand which is underlain by alternating layers of clay and sand. Since several layers of sand separated by clay are present below the initial confining clay layer, it is probable that more than one deep confined aquifer exists in the study area. As shown on Figure 9, all of the wells are perforated below the upper, unconfined aquifer and many of the wells are perforated over more than one deeper sand layer. It is difficult therefore to determine how many confined aquifers are present with the well information which we have at the present time.

The lithology of the West Mesa area can be determined from the log of only one well, U.S. Geological Survey Well LCRP8 (14S/11E - 32R1). As shown on Figure 9, the subsurface materials are alternating layers of sand and clay. Without other well logs for comparison, it is not possible to evaluate whether the upper clay layer is a confining bed as in the San Sebastian Marsh area.

Well Tests

The productivity of the aquifers in the study area has been evaluated by studying the results of well tests from 31

FIGURE 9 STRATIGRAPHIC RELATIONSHIPS OF WELLS IN THE SAN SEBASTIAN MARSH STUDY AREA



wells. The data are presented in Appendix 2. Of the 31 wells which have well test information, 19 wells are in the recharge area, the Lower Borrego Valley (T12S/R8E) and the eastern Borrego Valley (T11S/R7E and T12S/R7E). Ten of the wells are in and around the San Sebastian Marsh, eight at Ranch Oasis and two at the eastern border of the marsh. Of the remaining two wells, one is in the hills north of the marsh area (T11S/R10E - 35N1) and the other is in the West Mesa area south of the marsh (T14S/R11E - 32R1). One measure of the productivity of a well is the specific capacity, which is the production rate divided by drawdown. It is preferable to compare specific capacity among wells in order to assess productivities of the aquifers. However, not all of the well tests reported drawdown.

The wells in the Lower Borrego Valley range in production from 30 to 1300 gallons per minute. Of the well tests reported, only three have drawdown data. These wells have production rates of 220, 400 and 1000 gallons per minute with specific capacities of 31, 33 and 250 gallons per minute per foot of drawdown. As discussed previously, it appears that these wells are producing from an unconfined aquifer which provides recharge to the uppermost confined aquifer in the marsh area. From the well tests it appears that wells penetrating the upper aquifer in the Lower Borrego Valley produce from 30 gallons per minute per foot of drawdown to as much as 250 gallons per minute per foot of drawdown with production rates of 400 to as much as 1000 gallons per minute or more.

The wells in the San Sebastian Marsh area are shown on Figure 10. Information from ten wells which have well tests are on the figure. The eight wells in the Ranch Oasis area range in production from 1400 to 3700 gallons per minute with specific capacities ranging from 23 to 176 gallons per minute

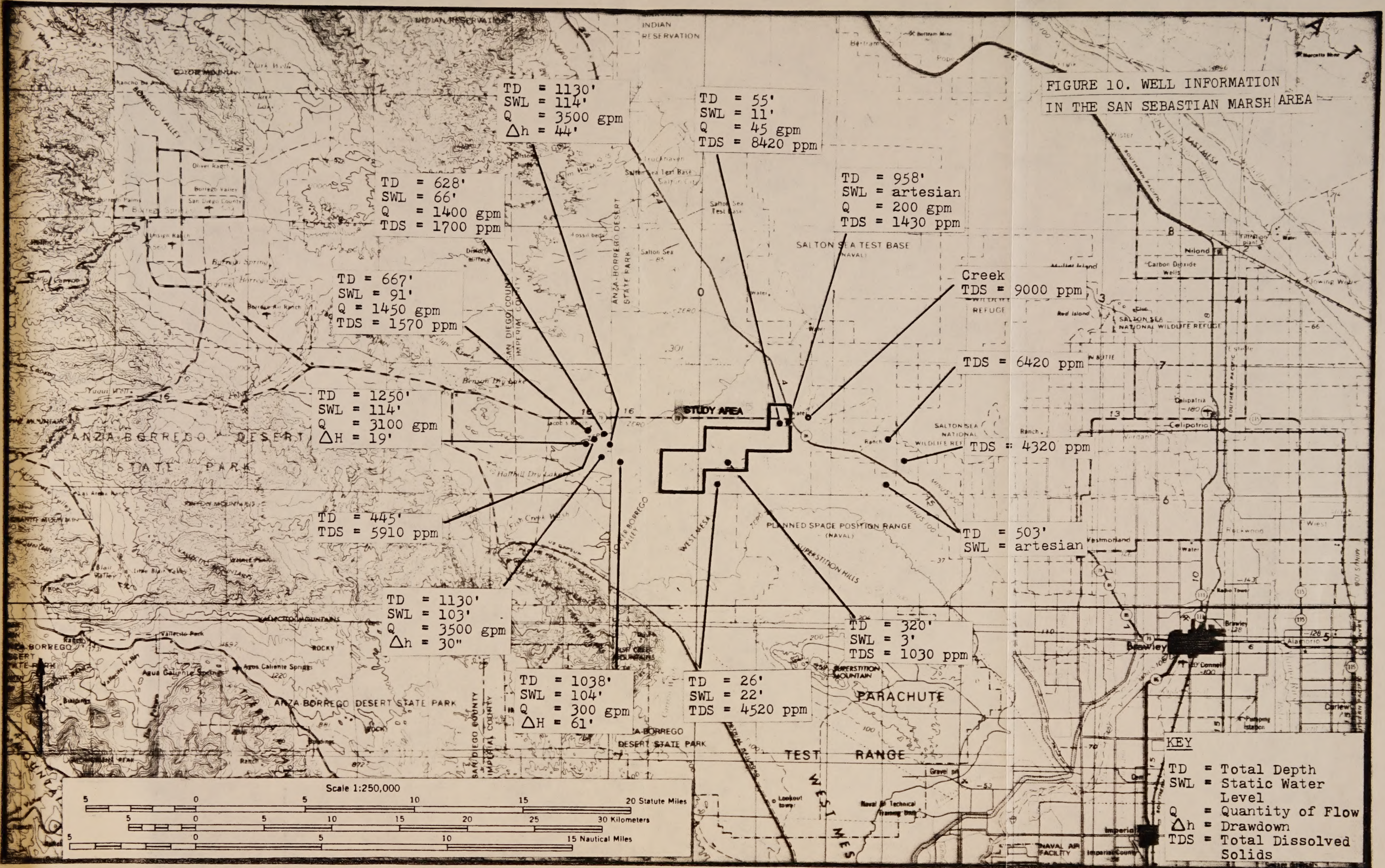


FIGURE 10. WELL INFORMATION IN THE SAN SEBASTIAN MARSH AREA

per foot of drawdown. All of these wells are producing from the confined aquifer(s) below the uppermost confining clay layer as shown on Figure 9. The U.S. Geological Survey well (LCRP19 and 19A) at the eastern border of the marsh area was completed in two sections, one in the upper unconfined aquifer above a depth of 100 feet and the other in the confined aquifer(s) below a depth of 300 feet, as shown on Figure 9. The lower section produces 200 gallons per minute with a specific capacity of 50 gallons per minute per foot of drawdown. The upper section produces 45 gallons per minute with a specific capacity of five gallons per minute per foot of drawdown.

Wells producing from the confined aquifer(s) in the San Sebastian Marsh area are capable of producing about 100 gallons per minute per foot of drawdown with production rates of a few thousand gallons per minute. If the surface water in the marsh area is due to faulting across the San Felipe Creek floodplain a partial barrier to ground water flow may be present between the Ranch Oasis wells and the U.S. Geological Survey well near the intersection of the highways. If a partial barrier exists, production rates from wells east of the fault would be expected to be less. Well LCRP19 has a specific capacity less than the average of the Ranch Oasis wells but certainly within the range of those wells. Therefore, if faulting is present it may not form a very significant barrier.

The upper portion of the U.S. Geological Survey well, LCRP19, is the only well in the marsh area which provides production information on the upper, unconfined aquifer. The productivity of the upper aquifer with a specific capacity of five gallons per minute per foot of drawdown is shown to be substantially less than the confined aquifer(s).

The productivity of the West Mesa area can be estimated from the test data of only one well, U.S. Geological Survey Well LCRP8. This well produces 250 gallons per minute with a specific capacity of 18 gallons per minute per foot of drawdown. As shown on Figure 9, this well produces from beneath a layer of clay but the water level is not higher than the bottom depth of the clay. Therefore, this well may not be producing from a confined aquifer. With evidence from only one well, it appears that the West Mesa aquifer penetrated by well LCRP8 is capable of less production than the confined aquifer penetrated by the wells near San Sebastian Marsh.

In addition to production and drawdown collected from various references and shown in Appendix 2, Loeltz, et al. (1975, p. K17) presented transmissivity and permeability values determined from pumping tests of four wells, the U.S. Geological Survey wells LCRP19, LCRP19A and LCRP8 and one of the Ranch Oasis wells, T12S/R9E - 22A2. Wells LCRP19 and T12S/R9E - 22A2 test the lower confined aquifer in the marsh area, Well LCRP19A tests the upper unconfined aquifer in the marsh area and LCRP8 tests the aquifer in the West Mesa area. The results of these tests are presented below:

Well	Interval Tested-ft	Transmissivity gpd/ft	Permeability gps/ft^2
T12S/R9E-22A2	285-667	290,000	760
LCRP19	310-650	100,000	300
LCRP19A	35-55	37,000	1800
LCRP8	135-560	130,000	480

Geophysical Measurements

Geophysical data for the study area consists of geophysical logs in six wells. Written summaries of resistivity

and self potential logs were obtained from Koebi and Koebig, Inc. (1970, Table A-1) and Coachella Valley Pump and Supply, Inc. for four of the Ranch Oasis Wells, T12S/R9E - 22A2, 22A3, 25F1 and 26D1 (Ranch Oasis Wells 1, 3, 4 and 6). Resistivity, self potential, gamma ray and temperature log plots for the U.S. Geological Survey Wells LCRP19 and LCRP8 are from Loeltz, et al (1965, Plate 2). All of these data are presented in Appendix 6. The logs show alternating layers of high and low resistivity corresponding to the alternating sand and clay layers observed in the lithologic logs.

Ground Water Level Elevation Records

Figure 11 shows a ground water level elevation contour map for the study area from water level measurements made in 1968. Most of the wells were measured in 1968 and thus afforded the most recent year for constructing a water level contour map. A total of 74 wells have at least one water level measurement. Water level data are presented in Appendix 2, and wells which have more than one measurement have all water level data presented in Appendix 3.

Water levels measured in the wells in the Ranch Oasis and San Sebastian Marsh areas are from the lower, confined aquifer. Water levels in the Lower Borrego Valley are from the upper, unconfined aquifer. As stated in the section on Lithology, the wells in the Lower Borrego Valley do not show any evidence of a confining clay layer. It is probable that the confined aquifer has limited extent to the west. Since no evidence of a lower confined aquifer exists in the Lower Borrego Valley, the confined aquifer in the study area probably begins near the western border to T12S/R9E. As stated previously, the western recharge area for the confined

aquifer in the San Sebastian Marsh area is the Lower Borrego Valley. Not enough well data exist to determine the southern limits of the confined aquifer, however, the U.S. Geological Survey well LCRP8 in West Mesa appears to be unconfined, which indicates that the southern limit of the confined aquifer is somewhere north of this well.

As shown on Figure 11, the water level contours continually decrease from west to east indicating subsurface flow which generally parallels the flow of San Felipe Creek and its tributaries. The Lower Borrego Valley has very good well control in T12S/R8E and, as shown, the movement of the ground water is from north to south in the northern half of the township. The movement then is to the southeast and out into the San Felipe Creek floodplain area. Indicated major directions of ground water movement are shown by solid lines on Figure 11.

In the West Mesa area, four wells have nearly the same water level elevation, about 30 feet. The elevation is more than 100 feet higher than in the marsh area and therefore water movement may occur from the West Mesa area to the north. However, there are no other water level data in T13S/R10E and T14S/R10E therefore the existance of a ground water divide must still be considered north of the four wells in the southeast corner of T14S/R10E. Since the surface water divide between Carrizo and Coyote Washes is southeast of these wells, such a ground water divide is most likely coincident with the surface divide. Verification of this interpretation would need additional study. The interpreted ground water divide shown on Figure 11 forms the southeast border of the ground water basin. It should be noted that the ground water divide shown on Figure 11 is very near the ground water divide shown on a water level contour map by the U.S. Geological Survey (Loeltz, 1975, Plate I).

As shown on Figure 11, a ground water divide is present through the group of wells in the western half of T11S/R7E and T12S/R7E. The divide is situated west of San Felipe Creek. As stated in the Hydrologic Setting Section of the report, it appears that the surface drainage has been captured. The ground water drainage, however, may still flow from west to east south of Borrego Mountain. Therefore the indicated ground water divide shown on Figure 11 may be the true divide between the San Felipe Creek and Borrego Valley ground water drainages at least south of Borrego Mountain. As shown on the U.S. Geological Survey topographic maps, Borrego Mountain and Borrego Sink Quadrangles (1960, 1:24,000), the surface drainage from Borrego Sink flows to the east and intersects with San Felipe Creek north of Borrego Mountain where San Felipe makes a sharp bend to the east. According to Moyle (1968, p. 4) surface and subsurface flow from Borrego Valley spills out from Borrego Sink and flows to the east into Lower Borrego Valley. This interpretation needs to be verified with further work. At the present time, the divide shown on Figure 11 seems to be a practical western boundary for the ground water basin in the study area.

Water level elevations have been measured in the study area since the early 1950's. Some wells have more than two measurements so that estimates of water level decline can be made. Of the wells with multiple measurements most have measurements in the early 50's and again in the mid 60's. In the lower Borrego Valley, 14 wells have measurements separated by 10-15 years. These wells declined an average of 11 feet with two wells showing maximum declines of 57 and 34 feet. Two of the Ranch Oasis wells have multiple water level measurements. From 1962 to 1968 the water level in well 12S/9E - 22A2 fluctuated with a decrease in water level of 10 to 30 feet. From 1953 to 1966, the water level in Well 12S/9E - 23D1

fluctuated with a decrease of 30 to 45 feet. One well in the west Mesa area, well 14S/10E - 25G1 shows a 14 ft decrease in water level from 1949 to 1960.

Aquifer Recharge, Discharge and Storage

In order to determine the amount of aquifer recharge and discharge a water budget analysis has been made; the methodology has been discussed previously. In this analysis, the terms of the water budget are considered for average annual conditions. Therefore change in ground water storage should be equal to zero and aquifer recharge will equal aquifer discharge.

As shown on Figure 5, the average annual precipitation over most of the study area is less than four inches and ranges from less than three inches to more than 16 inches over the San Felipe Creek drainage area. When precipitation shown on Figure 5 is multiplied by the drainage area, a mean annual volume of precipitation falling on the drainage area is determined to be 675,000 acre-feet.

As shown on Figure 6, the average annual actual evapotranspiration in most of the study area is less than four inches and ranges from less than three inches to more than 16 inches over the San Felipe Creek drainage area. When actual evapotranspiration shown on Figure 6 is multiplied by the drainage area, a mean annual volume of actual evapotranspiration from the drainage area is determined to be 635,000 acre-feet.

When the actual evapotranspiration is subtracted from precipitation, a residual of 40,000 acre-feet remains. This residual is the amount of water in the budget available for surface flow and infiltration to the ground water. Forty thousand acre-feet equals 6% of the precipitation total of

675,000 acre-feet. This percentage is reasonable when compared to previous studies in similar hydrogeologic and climatic settings where differences between evapotranspiration and precipitation have been found to equal 5-15% of the precipitation.

As shown on Figure 7, the mean annual surface runoff from the study area is less than 0.02 inch and ranges from less than 0.02 inch to more than 1 inch over the San Felipe Creek drainage area. When surface runoff shown on Figure 7 is multiplied by the drainage area, a mean annual volume of runoff from the drainage area is determined to be 45,000 acre-feet.

The calculated volume of runoff is nearly equal to the evapotranspiration-precipitation residual and it would appear at first glance that all of the available water goes to runoff with none remaining for infiltration to ground water. Hely and Peck (1964, p. B11) state however, that the amount of runoff shown on Figure 7 which is adapted from Plate 5 of their report is equal to locally derived direct runoff and does not necessarily represent the amount of surface flow which reaches the major drainages in the alluvial basin. This is because no allowance was made for streamflow depletion from the streamcourses at the permeable edges of the basin.

The portion of the 40,000 acre-feet available for runoff plus infiltration can be determined by subtracting gaged runoff on San Felipe Creek from this total. Bradshaw and Donnan (1952, p.7) state that average annual runoff from San Felipe Creek equals 600-1000 acre-feet. From data provided by Werner and Olson (1970, p. 29) average annual runoff in San Felipe Creek gaged at Highway 86 from 1961 to 1967 equals 3250 acre-feet. Using this figure as a more conservative estimate

about 37,000 acre-feet is available for infiltration to the ground water basin from the entire San Felipe Creek drainage area.

Outflow from the basin to the Salton Sea can be calculated using Darcy's Law. The cross-sectional width is considered to be between the lacustrine sediment hills to the north and south on either side of San Felipe Creek. This distance is equal to about nine miles, or approximately 47,500 feet. To calculate outflow, the upper unconfined aquifer and the lower confined aquifer are both considered. From well tests of the U.S. Geological Survey wells LCRP19 and LCRP19A, the transmissivity of the upper aquifer is 37,000 gallons per day per foot and the transmissivity of the lower aquifer is 100,000 gallons per day per foot. The hydraulic gradient can be determined by the change in water level between the Ranch Oasis wells and Well LCRP19. The difference in water level is 60 feet over a distance of nine miles parallel to the axis of ground water flow. Since faulting may cross the San Felipe Creek floodplain between the two wells, this gradient may be erroneous. As another estimate, the ground water gradient can be considered to equal the land surface gradient between these wells, approximately 160 feet in nine miles. The average of these values, 110 feet in nine miles, was used in the calculation. The resulting flow is:

$$Q_{\text{upper aquifer}} = (37{,}000\text{gpd/ft})(110\text{ ft}/47{,}500\text{ ft})(47{,}500\text{ ft})$$

$$Q_{\text{lower aquifer}} = (100{,}00\text{ gpd/ft})(110\text{ ft}/47{,}500\text{ ft})(47{,}500\text{ ft})$$

$$Q_{\text{total}} = 4{,}000{,}000\text{ gpd (upper)} + 11{,}000{,}000\text{ gpd (lower)}$$

$$Q_{\text{total}} = 15{,}000{,}000\text{ gpd or }17{,}000\text{ acre-feet per year}$$

Werner and Olson (1970, p.31), Loeltz et al (1975, p.K20) and System Development Corporation (1979, p.I-72) all estimated

the outflow as 10,000 acre feet per year. Koebig and Koebig, Inc. (1970, p.20) estimated the outflow as 2240 acre-feet per year, but used a cross-sectional width of only five miles and a gradient of only four feet per mile to arrive at their calculation. In addition, they did not consider outflow from the upper aquifer.

Under average annual conditions with no change in ground water storage, outflow should equal recharge. As discussed, average annual outflow is estimated at 17,000 acre-feet and average annual recharge by infiltration is estimated at 37,000 acre-feet. Considering that these values were derived independently, the results are very close. A conservative estimate of average annual recharge to the ground water basin of the study area can be considered to be on the order of 20,000 acre-feet.

Some workers have considered that recharge to the lower San Felipe Creek drainage area is negligible (Koebig and Koebig, Inc., 1970, p.10) and (System Development Corporation, 1979, p.I-14). We have conservatively estimated that the area receives 20,000 acre-feet per year of recharge.

As stated previously, the amount of ground water in storage was determined by the specific yield method. The surface area of the ground water basin below Lower Borrego Valley, including West Mesa north of the ground water divide equals approximately 170,000 acres or 270 square miles. In this area, wells exist which penetrate more than 1000 feet of alluvial sediments. Assuming alternating clay and sand layers are equally proportioned, approximately 500 feet of potential aquifer sand layers are present. When multiplied by the surface area, this results in 85 million acre-feet of saturated aquifer volume. A reasonable value for specific yield for these aquifers is 10%(Todd, 1959, p.25). When the specific yield of 10% is multiplied by 85 million acre-feet of saturated aquifer volume, the estimated amount of ground water in storage equals 8.5 million acre-feet.

Estimates by other workers of ground water in storage in the study area range from four million acre-feet (System Development Corporation, 1979, p.I-19) to 120 million acre-feet (Dutcher and Hardt, 1972, p.46).

SURFACE HYDROLOGY

The discussion of the surface hydrology of the study area is based primarily on two on-site investigations of the San Sebastian Marsh area.

Surface Water Flow Records

The only suface flow gage in the study area is on San Felipe Creek where it crosses underneath Highway 86. In a study by Bradshaw and Donnan (1952, p.7), the average annual surface runoff of San Felipe Creek was estimated as 600 to 1000 acre-feet. The only published record of gaging on San Felipe Creek was in Werner and Olson (1970, p.29) which reports annual surface runoff from 1961 to 1967. The average of these totals is 3250 acre-feet per year but the range is great. The yearly totals are presented below:

Year	Surface Runoff - Acre-feet
1961	1130
1962	370
1963	8700
1964	100
1965	830
1966	2510
1967	9080

Areal Extent of Surface Water

On-site reconnaissances of the San Sebastian Marsh wetland area were made on May 15-17, 1980 and August 18-19, 1980. The stream bottoms in the wetland area were examined and the presence of standing and flowing water was noted. The size of significant bodies of water was measured. The following description of the

Evaluated by [illegible] in the
study area [illegible]
[illegible]
([illegible] and [illegible], [illegible]).

[illegible]

The discussion of [illegible]
[illegible]
[illegible]

[illegible]

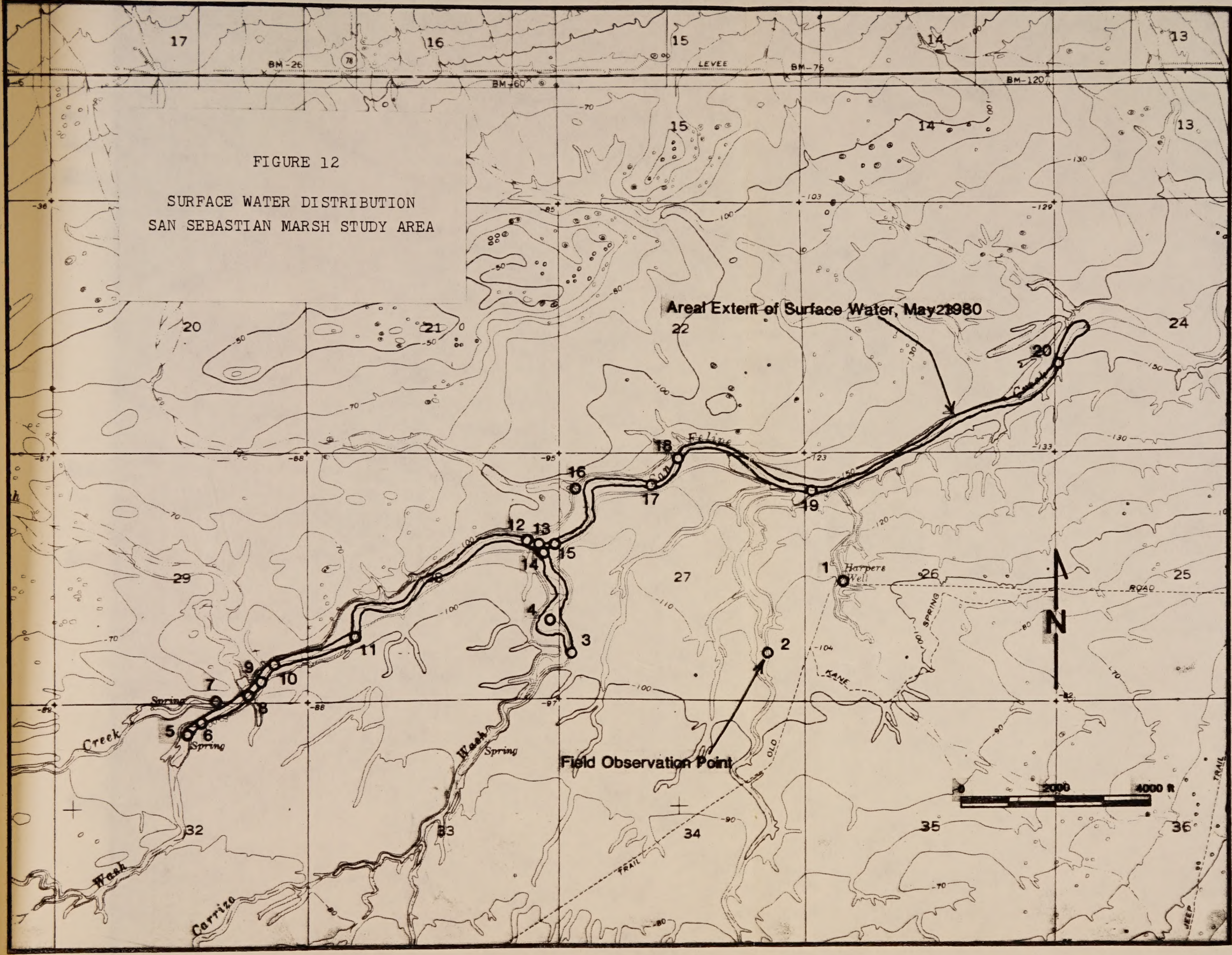
[illegible]

[illegible]

[illegible] and August [illegible]. The
[illegible]
[illegible]
[illegible]

FIGURE 12

SURFACE WATER DISTRIBUTION
SAN SEBASTIAN MARSH STUDY AREA



wetland area refers to specific sites shown on Figure 12, which are numbered generally upstream to downstream, west to east:

Site 1 Harper's Well Wash - Standing surface water is supported by flow from a well casing which extends about 1½ ft out of the stream bottom. During both visits, a body of water approximately 20 ft long and 1 ft wide was present downstream from the casing. In May, a 4 ft diameter pool had fish and tadpoles, but this had dried by August. In August, water from the well had a conductivity of 1800 mmhos/cm (approx. 1150 mg/l TDS). Dark areas on air photos upstream and downstream from the well were checked. The stream bottoms had lush vegetation but no surface water.

Site 2 Tributary west of Harper's Well Wash - Dark areas on the air photos were checked and the stream bottoms were found to have lush vegetation but no surface water.

Site 3 Carrizo Wash - During the May visit, two ponds at this site were the furthest upstream occurance of surface water. The upstream pond in May was 25 ft long, 6 ft wide and 8 in deep. One hundred feet downstream, the second pond measured 7 ft long 2½ ft wide and 6 in deep. No animals were seen in either pond. During the May visit, about 100 ft north (downstream) of the ponds, surface flow in Carrizo Wash began with a flow 1-2 feet wide. During the Augustvisit all of this area as dry.

Site 4 Carrizo Wash - This large meander loop was a marshy area with standing and flowing water in May. During the August visit, the only surface water observed in Carrizo

Wash were pools of standing water in this meander loop.

Site 5 Fish Creek Wash - During the May visit, two ponds at this site were the furthest upstream occurance of surface water in the wetland area. The upstream pond in May was 40 ft long, 5 ft wide and 6 in deep. About 150 ft downstream the second pond measured 15 ft long, 8 ft wide and 6-8 in deep. No animals were seen in either pond. Both of these ponds were dry during the August visit.

Site 6 Fish Creek Wash - During the May visit, there was a pond at this site, 110 ft long, 3-4 ft wide and 1 ft deep. Fish and tadpoles were seen in the pond. During the August visit, this area was dry.

Site 7 San Felipe Creek - San Felipe Creek was dry above the confluence with Fish Creek Wash during both visits.

Site 8 San Felipe Creek - A large pond of standing water was present during both visits. During both visits, the pond was 200-250 ft long, 6 ft wide and 1-2 ft deep. The northeast 100 ft of the pond tapered from 6 ft wide to less than 1 ft wide at the northeast end of the pond. The northeast end was approximately 100 ft southwest of the confluence with Tarantula Wash. Fish and tadpoles were observed in all the bodies of water downstream from this site during both visits.

Site 9 San Felipe Creek - During the May visit, a pond of Standing water was present at this site, 50 ft long, 5 ft wide and 8 in deep. The west end of the pond was approximately 300 ft northeast of the confluence with Tarantula Wash. This pond was dry during the August visit.

Site 10 San Felipe Creek - During both visits a pond was

present at this site. During the May visit it was 200 ft long, 12 ft wide and 1 ft deep. During the May visit, this pond was the beginning of the flowing surface water with a 1 ft wide flow beginning at the east end of the pond. During the August visit, this was a pnd of standing water, only 50 ft long, 5 ft wide and 6 in deep.

Site 11 San Felipe Creek - During both visits, a pond was present at this site. It was pear shaped, 200 ft long, 50 ft wide at the west and tapering down to 15 ft wide at the east end and 3-4 ft deep. During the August visit, this pond was the beginning of flowing surface water. Between Sites 11 and 12, a marshy area of flowing water about 10-20 ft wide was present. In August, the water in the pond had a conductivity of 18,500 mmhos/cm (approximately 12,000 mg/l TDS).

Site 12 San Felipe Creek - Approximately 100 ft upstream from the confluence with Carrizo Wash was a cigar shaped pond tapering at both ends into swampy areas. The pond in August was 200 ft long, 15 ft wide and 1 ft deep. In May, the pond had been 20 ft wide and 1-2 ft deep.

Site 13 San Felipe Creek - A constriction was present at this site, downstream from the pond at Site 12 and directly upstream from the confluence with Carrizo Wash. This constriction allowed measurement of surface flow. A water sample in August had a conductivity of 14,000 mmhos/cm (approximately 9000 mg/l TDS).

Site 14 Carrizo Wash - A constricted area at the mouth of Carrizo Wash allowed measurement of surface outflow during the May visit. There was no surface outflow during the August visit.

Site 15 San Felipe Creek - Immediately downstream from the confluence with Carrizo Wash was a kidney shaped pond, 200-250 ft long, 10-20 ft wide and 1 ft deep. The pond was the same size during both visits but the depth during May was 1-2 ft. A water sample in August had a conductivity of 14,000 mmhos/cm (approximately 9000 mg/l TDS). From Site 15 to Site 17 the surface flow was approximately 5 to 10 ft wide.

Site 16 Tributary to San Felipe Creek - During the May visit, a small pond 200 ft upstream from the confluence with San Felipe Creek was fed by a spring with a small amount of flow. The pond was 50 ft long. During the August visit, this area was dry.

Site 17 San Felipe Creek - During both visits, a pond 100-125 ft long, 20-40 ft wide and 1-2 ft deep was observed.

Site 18 San Felipe Creek - During both visits, a small 1-1½ft waterfall was observed upstream from two ponds. The upper pond was 150 ft long, 25 ft wide and 1 ft deep. The lower pond was 100 ft long, 15 ft wide and 6-8 in deep. From Sites 17 to 19, the surface flow was about 10 ft wide.

Site 19 San Felipe Creek - Near the confluence with Harper's Well Wash, the surface flow narrowed from 10 ft to 3-5 ft for a stretch of about 100-200 ft. During the August visit, the flow continued to decrease until it disappeared within 500 ft downstream from this site. During the May visit, the surface widened to 5-10 ft and continued downstream to Site 20.

Site 20 San Felipe Creek - The surface flow during the May visit decreased from a 5-10 ft wide flow at this point, to a swampy area, and within 500 ft downstream from this site, no more surface water was observed.

A stated, the areal extent of standing and flowing surface water in the San Sebastian Marsh wetland area changed from May 15, 1980 to August 18, 1980. During the May visit, standing surface water started at Site 5 and flowing water started at Site 10 and continued downstream to Site 20. During the same visit, flowing water was also observed from Site 3 to Site 14 in Carrizo Wash. During the August visit, standing water started at Site 8; flowing water started at Site 11 and extended downstream to Site 19. No flowing surface water was observed in Carrizo Wash during the August visit; standing water was observed at Site 4.

Measurements of Surface Water Flow

It was hoped that flowing springs which provide surface water for the San Sebastian Marsh wetland area could be located and measured. The U.S. Geological Survey topographic map, Harper's Well Quadrangle (1956, 1:24,000) shows springs in San Felipe Creek (T12S/R10E - 32C), in Fish Creek Wash (T12S/R10E - 32B) and in Carrizo Wash (T12S/R10E - 33B). During field investigations, no identifiable springs were found. The surface water started as diffuse damp and wet area, then standing bodies of water and finally flowing surface water, all as a gradual transition. The only observed surface water near the mapped springs was in Fish Creek Wash where ponds were found near the mapped spring during the May visit.

It is possible that the surface water in San Sebastian Marsh is due to faulting through the confining clay layer, which allows water from the lower, confined aquifer to move upwards and mix with the upper aquifer. This would result in a gradual appearance of surface water, whereas, faulting to the ground surface would tend to result in an identifiable spring.

Surface flow measurements were made on San Felipe Creek, directly upstream from the confluence with Carrizo Wash (Site 13, Figure 12). The flow was determined by measuring the velocity of flow through the constricted area and multiplying the result by the cross-sectional area of the constriction. During both the May and August visits the flow was determined to be approximately 0.2 cubic ft per second. Surface outflow from Carrizo Wash was also measured during the May visit. A weir was constructed and flow was measured through a known cross-sectional area. This flow was determined to be approximately 0.1 cubic ft per second.

RECOMMENDATIONS

IDENTIFICATION OF SUITABLE GROUND WATER MODELS

The selection of a suitable ground water model involves the choice of the most appropriate approach; finite difference method or finite element method, the most appropriate grid network and the most apprpriate matrix solution technique.

Models using the finite difference and finite element methods have been well documented by various workers (Trescott, 1975), (Trescott, Pinder and Larson, 1976) and (Mallory, 1979). Each study area requires modifications of the basic methods. Since the geohydrology of the San Sebastian Marsh area is not completely understood at this time, it would seem that a finite difference model would be the most appropriate to begin with. As stated previously, the finite difference method has a more straight forward theoretical basis and is easier to program than the finite element method. In the early stages of developing a model for this area, the first outputs will help to better understand aquifer behavior. This better understanding may

necessitate changes in the program. Therefore, the finite difference method should be more practical because of the easier programming.

The choice of a grid network is more difficult. Basically, one must choose between a rectangular and a polygonal grid. The rectangular grid is easier to use and involves less data input due to the orientation of the grid axes parallel to the direction of ground water flow which is presumed to also be the direction of maximum transmissivity. The polygonal grid can be designed to better fit the shape of the basin shown on Figure 13. It allows more flexibility to make the nodes smaller in areas with a greater concentration of data and larger in areas with little or no data. Thus, a polygonal grid will most likely have fewer total nodes than a rectangular grid of the area. If a choice is to be made at this time, the polygonal grid would seem more practical due to the greater flexibility of nodal size.

The choices of matrix solution technique are the direct method and the iterative method. Since the iterative method is more efficient in computer time and storage, it is the more practical method to use. The iterative method of solution has several variations, including the alternating direct implicit method, the strongly implicit procedure, line successive over-relaxation and point successive over-relaxation. All require an initial guess of the matrix solution and error criteria. The choice of variation is strongly problem dependent, as the major objective of each is to minimize the number of passes through the matrix before convergence within the error criteria is reached. The alternating direction implicit method is the most widely used and the best documented of these variations.

The boundary and boundary conditions must be specified. The most practical boundaries for the San Sebastian Marsh area are shown on Figure 13. These boundaries have been selected using the present geohydrological understanding of the area. For practical purposes, three types of boundary conditions should be initially considered. No-flow conditions form most of the boundary. This type of condition implies an impermeable boundary. The only true impermeable boundary is in the southwest, at the base of the Fish Creek Mountains, and other exposures of basement complex to the west and south at the base of Superstition Mountain. The northern boundary and the boundary to the east, along the base of the Superstition Hills have also been designated as no-flow boundaries. These areas are composed of older, tighter sediments. While they undoubtedly store and transmit water, the transmissivity of these sediments is probably negligible in comparison to the transmissivity of the sediments in the San Felipe Creek floodplain. As the model develops, it may indicate that these boundary conditions should be modified. The presumed ground water divides are to the west and south. These boundaries should initially be considered constant-head boundaries. If extensive ground water development occurs close to these boundaries, this condition will have to be modified. To the east, the Salton Sea represents a constant-head boundary. Finally, two small areas where San Felipe Creek and Fish Creek enter the basin should be considered as constant-flux boundaries, since inflow to the basin occurs at these two areas.

IDENTIFICATION OF ADDITIONAL DATA REQUIREMENTS

Additional data required for the study of the geohydrology of the San Sebastian Marsh area will consist of input for the ground water model, and data needed to better define the geohydrology of the area.

define the geohydrology of the area. Ideally, at least one observation well should be available for each node of the ground water model. The study area, at present, is devoid of any wells.

Observation wells are also needed to better define the ground water movement and to provide water level data as input, and for verification of the model. Since well drilling is costly, a program of well drilling should be established to fill in the empty area over some period of time. The first drilling should be done in the marsh area. One well should be placed west of the westernmost limit of surface water in the marsh and another well should be placed east of the confluence of Carrizo Wash and Fish Creek. These two locations are presumed to be on opposite sides of faulting through the marsh area. Other wells should be located south and southwest of the marsh area. Any wells drilled should have accurate lithologic logs. Downhole geophysical logs, at least resistivity and self potential should be run in each well. Consideration should be given to multiple completions of wells, with one completion above the clay layer and at least one completion below. The different zones should be test pumped to determine aquifer parameters.

A yearly inventory of water levels in all available wells in the study area (Figure 8) should be made. This should be done in the late summer when water levels are most stable. If possible, an additional set should be obtained in the spring for comparison of seasonal differences.

A stream gage on San Felipe Creek at Highway 86 should be reinstituted, so that surface outflow from the basin can be measured.

Continued mapping of the distribution of surface water in

the San Sebastian Marsh should be done on a periodic schedule to document the base conditions in the marsh prior to any further ground water development. The flow in San Felipe Creek should be measured at the confluence with Carrizo Wash during on-site visits.

Other surface hydrologic data which will be needed to determine aquifer recharge will be precipitation measurements and stream flow measurements. Several gages placed throughout the study area, especially in the upper reaches would be used to relate stream flow measurements to changes in recharge. Gages should be placed where San Felipe Creek, Fish Creek Wash and Carrizo Wash enter the study area.

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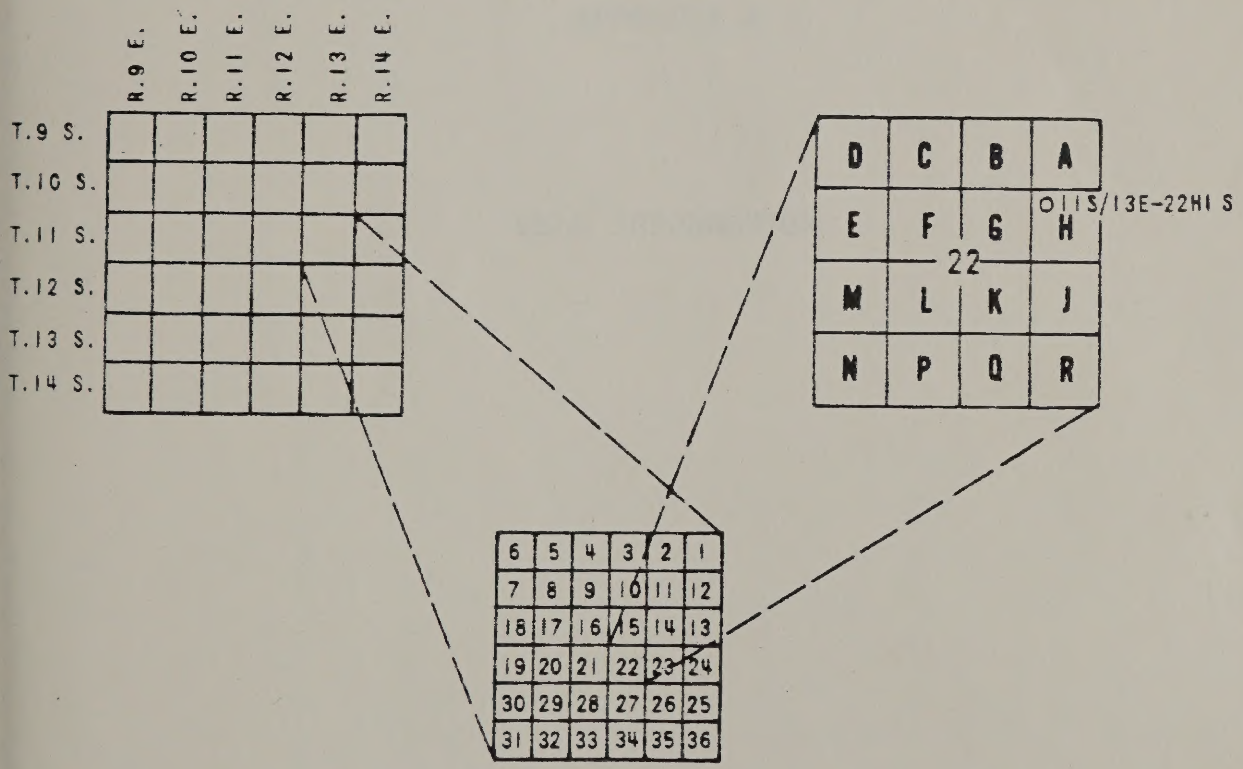
APPENDIX 1

WELL NUMBERING SYSTEM

WELL-NUMBERING SYSTEM

The well-numbering system in Imperial Valley has been used by the Geological Survey in California since 1940 and is in accordance with the Bureau of Land Management's system of land subdivision. The system has been adopted by the California Department of Water Resources, California Water Resources Control Board, and many local water districts. As shown by the example in the accompanying diagram, that part of the number preceding the slash, as in well number 11S/13E-22H1 S, indicates the township (T. 11 S.); the number following the slash indicates the range (R. 13 E.); the number following the hyphen indicates the section (sec. 22); the letter following the section number indicates the 40-acre (16-ha) subdivision (H) according to the lettered diagram below. The final digit is a serial number for wells in that 40-acre (16-ha) subdivision; it indicates the first well to be listed in the SE¼NE¼ sec. 22, T. 11 S., R. 13 E. The area covered by this report lies east of the San Bernardino meridian and south of the San Bernardino base line. The letter S at the end of the well number indicates the San Bernardino base line and meridian designation.



APPENDIX 2

WELL INFORMATION

WELL INFORMATION

						WELL TESTING			
Location	Name	Year Drilled	Surface Elevation (ft)	(ft) Well Depth	Perf. Interval (ft)	Date Measured	(ft) Static Level	(gpm) Discharge	(ft) Drawdown
11S/7E-6N1			520	3					
7K1			480	9			Dry		
7N1		1936	475	140		11-53	28.8*	500	
8N1			480	2			Dry		
17X1			452						
20P1		1951	595	368		12-53	79.0*	450	8.0
29C1			590			7-65	70.8		
30G1			520	69		7-65	61.2*		
30G2		1925	555	89		7-65	75.2*		
30G3			560	350		7-65	70.0	250	20.0
30K1		1925	555	83		12-53	72.0	25	
30K2		1950	565	146		2-53	96.9		
32Q1		1952	700	463	267-418	12-53	188.0*	100	80.0
11S/8E-25J1		1932	140	847					
25J2			140	4					
33P1		1960	173	436	266-436	8-65	58.1		
33P2			173	9			Dry		
11S/10E-10E1		1950	115	2547					
31E1		1951	150	4314					
32J1		1933	104	4115					
35N1		1960	50	809		-60	181.0*	12	

* Additional Water Level Data in Appendix 3

WELL INFORMATION

						WELL TESTING			
Location	Name	Year Drilled	Surface Elevation(ft)	(ft) Well Depth	Perf. Interval (ft)	Date Measured	(ft) Static Level	(gpm) Discharge	(ft) Drawdown
12S/7E-4J1			740	642		8-65	278.5	100	41.0
12S/8E-2N1			180						
3R1		1939	180	3912					
4H1			160	48		8-65	dry		
4N1			288	13		8-65	dry		
4N2		1965	288	265		8-65	159.8		
6H1		1958	380	300					
6J1			400			8-65	185.4		
6N1			440			8-65	198.1		
6N2			440			8-65	210.4		
6P1		1952	410	314	194-314	8-65	194.4*		
6P2		1954	410	216		8-65	189.5*		
6R1			360			8-65	195.9		
6R2			360			8-65	187.5		
7R1			400	10		8-65	dry		
8K1		1950	295			8-65	244.1*		
8K2		1965	300	285		8-65	240.8*	30	
8M1			360	360		1-54	277.0		
9A1		1963	160	209		8-65	101.9		
9H1		1952	185	176	100-174	10-52	128.0		
9H2			190	156		8-65	150.8		

* Additional Water Level Data in Appendix 3

WELL INFORMATION

						WELL TESTING			
Location	Name	Year Drilled	Surface Elevation(ft)	(ft) Well Depth	Perf. Interval (ft)	Date Measured	(ft) Static Level	(gpm) Discharge	(ft) Drawdown
12S/8E-9J1			180	220		8-65	149.1*		
9J2		1964	180	318	270-295	8-65	138.0*		
9J3		1959	190	250	150-250	2-59	140.0*	220	7.0
10B1		1965	175	43		8-64	53.7*		
10E1			160	115		12-53	112.0*		
10E2			165	142					
10E3			170	200		8-65	140.1		
10E4			160			8-65	59.1		
10M1		1958	165	246		8-65	123.1		
10N1		1950	156	222	139-219	12-53	120.0*	400	
10N2		1952	155	232		3-52	116.0	400	12.0
10N3		1964	155	243		8-65	117.0		
10Q1			155	108		8-65	103.0		
10Q2		1963	155	218		8-65	101.5	90	
12R1			82	30		8-65	dry		
15C1			150			8-65	114.8		
15E1			160	222	116-190	8-65	133.5*		
15E2			155			8-65	142.0		
15K1		1961	150	301		8-65	120.1	1000	4.0
15M1		1952	155	297		8-65	142.1		
15N1		1965	135	200	140-170	8-65	118.0*		

* Additional Water Level Data in Appendix 3

WELL INFORMATION

						WELL TESTING			
Location	Name	Year Drill-ed	Sur-face Eleva-tion(ft)	(ft) Well Depth	Perf. Inter-val (ft)	Date Meas-ured	(ft) Static Level	(gpm) Dis-charge	(ft) Draw-down
12S/8E-15X1		1925	135	150		-25	125.0		
16R1			140	193					
17P1			300	254		8-65	219.6*		
17X1		1925	209	202		-25	176.0		
22E1		1929	110	226		8-65	109.4*	675	
22K1		1958	95			8-65	89.1	1300	
22R1			75	56		11-53	Dry		
23F1			140						
24Q1			80	220		12-53	85.6*	500	
25G1			40	65		12-53	Dry		
25X1		1926	50	245		-26	53.0	30	
26C1		1925	75	120		-25	87.0	20	
26H1			60	64		8-65	62.3		
27A1			70	83		8-65	73.3		
27B1		1947	80	214		12-53	71.0	200	
27D1			114	156		8-65	117.2*		
27F1			100	122	82-122	-26	81.0*	26	
12S/9E-21N1			5	1280					
22A1		1953	-13	445	312-412	8-65	105.3		
22A2	Ranch #1	1961	-12	729	380-667	3-68	115.0*	1580	9.0
22A3	Oasis #3	1967	-15	1250	270-1200	2-68	114.0	3760	23.0

* Additional Water Level Data in Appendix 3

WELL INFORMATION

						WELL TESTING			
Location	Name	Year Drilled	Surface Elevation(ft)	(ft) Well Depth	Perf. Interval (ft)	Date Measured	(ft) Static Level	(gpm) Discharge	(ft) Drawdown
12S/9E-22B1		1967	-12	1250	270-1200	6-67	114.0	3100	19.0
23D1		1953	-15	580	250-565	12-53	64.2*	1400	60.0
23D2	Ranch #2	1965	-15	675	260-674	2-68	115.0	1500	13.0
23K1	Oasis #5		-30	1130	350-1120		114.0	3500	44.0
25F1	Oasis #6		-50	1038	380-1000	12-76	104.0	3000	61.0
26D1	Oasis #4		-30	1130	380-980	10-76	103.0	3500	30.0
27B1			-20			8-65	76.2		
29A1			0	18		8-65	Dry*		
30M1			38	59		1-66	45.7*		
34C1		1914	-20	500					
12S/10E-26M1		1899	-130	320		5-80	Flowing*		
34G1			-95	26		9-62	21.6*		
12S/11E-18J1	LCRP19	1964	-175	959	310-650	7-64	Flowing	200	4.0
18J2	LCRP19A	1964	-175	55	35-55	7-64	11.3	45	8.0
36K1		1959	-130	503	352-422	-59	Flowing		
13S/9E-2N1			20	1185	300-1100				
18X1		1909	230						
24K1			-5			1-49	48.8		
25Q1			0	40		8-65	31.3		
13S/10E-5X1		1913	-75	662					

* Additional Water Level Data in Appendix 3

WELL INFORMATION

						WELL TESTING			
Location	Name	Year Drilled	Surface Elevation (ft)	(ft) Well Depth	Perf. Interval (ft)	Date Measured	(ft) Static Level	(gpm) Discharge	(ft) Drawdown
14S/10E-25G1			84	126		11-60	Dry*		
25G2			84			-62	Dry*		
25R1			92	248		-62	Dry*		
14S/11E-32R1	LCRP8	1962	88	985	135-560	-62	120.8*	250	14.0
ADDITIONAL DATA									
12S/9E-22A2						7-63	91.0	1580	14.0
						8-63	105.8	1450	16.0
						2-68	115.0	1450	9.0
						3-68	115.0	1580	9.0

* Additional Water Level Data in Appendix 3

APPENDIX 3

WATER LEVEL DATA

WATER LEVEL DATA

LOCATION	DATE	LEVEL	LOCATION	DATE	LEVEL
11S/7E-7N1	11-53	28.8	11S/7E-20P1	3-56	74.8
	2-54	28.3		11-56	73.8
	11-54	29.6		3-57	72.7
	3-55	29.1		11-57	71.8
	11-55	30.2		11-58	71.8
	3-56	29.9		3-59	71.2
	11-56	30.9		11-59	70.9
	3-57	31.5		2-60	70.8
	11-57	31.8		11-60	70.7
	3-58	31.3		3-61	70.6
	11-58	32.8		10-61	70.4
	3-59	32.2		3-62	70.4
	11-59	33.5		11-62	70.4
	2-60	33.1		3-63	70.3
	11-60	33.5		10.63	70.2
	3-61	33.2		3-64	70.0
	10-61	34.2		11-64	70.6
	3-62	33.8		3-65	71.0
	11-62	34.7		7-65	70.7
	3-63	34.5		10-65	70.7
	3-64	34.8		3-66	71.7
	11-64	38.4	11S/7E-30G1	12-53	61.3
	3-65	38.6		7-65	61.2
	10-65	36.0	11S/7E-30G2	2-53	76.2
11S/7E-20P1	2-53	72.5		12-53	76.8
	12-53	80.0		7-65	75.2
	2-54	73.1	11S/7E-32Q1	11-52	195.0
	11-54	81.7		12-53	188.0
	3-55	79.7		11-54	188.0
	11-55	82.6		7-65	192.0

WATER LEVEL DATA

LOCATION	DATE	LEVEL	LOCATION	DATE	LEVEL
12S/8E-6P1	5-52	189.0	12S/8E-15N1	5-65	120.0
	12-53	179.8		8-65	118.0
	2-54	180.0	12S/8E-17P1	1-54	209.4
	11-54	180.0		8-65	219.6
	3-55	180.3	12S/8E-22E1	12-53	101.0
	8-65	194.4		2-54	102.2
12S/8E-6P2	11-54	182.2		11-54	101.8
	8-65	189.5		3-55	101.9
12S/8E-8K1	12-53	240.0		11-55	101.9
	8-65	244.1		3-56	101.2
12S/8E-8K2	2-65	240.0		11-56	101.9
	8-65	240.8		3/57	101.9
12S/8E-9J1	1-49	115.0		11-57	101.9
	8-65	149.1		3-58	102.0
12S/8E-9J2	5-64	138.0		11-58	105.6
	8-65	138.0		3-59	105.9
12S/8E-9J3	2-59	140.0		11-59	108.6
	8-65	139.6		2-60	108.6
12S/8E-10B1	12-53	Dry		11-60	108.8
	8-64	53.7		3-61	109.4
12S/8E-10E1	2-49	55.0		10-61	110.1
	12-53	112.0		3-62	110.5
12S/8E-10M1	5-58	125.0		11-62	112.5
	8-64	110.0		3-63	113.3
	8-65	123.1		10-63	113.8
12S/8E-10N1	9-50	117.0		3-64	113.9
	8-65	119.9		11-64	109.9
12S/8E-15E1	1-49	133.0		3-65	111.0
	12-53	131.8		10-65	109.3
	8-65	133.5		3-66	110.0

WATER LEVEL DATA

LOCATION	DATE	LEVEL	LOCATION	DATE	LEVEL	
12S/8E-24Q1	12-53	85.6	12S/9E-23D1	3-61	79.1	
	1-54	85.6		10-61	134.7	
	8-65	99.9		3-62	135.6	
12S/8E-25G1	9-49	64.5		L1-62	141.1	
	12-53	Dry		3-63	142.6	
12S/8E-27D1	12-53	113.6		10-63	142.9	
	8-65	117.2		3-64	87.9	
12S/8E-27F1	-26	81.0		3-65	95.4	
	1-49	86.8		8-65	110.1	
	12-53	86.7		10-65	108.3	
12S/9E-22A2	5-62	85.0		3-66	109.3	
	3/63	101.7	12S/9E-29A1	1-49	Dry	
	7-63	91.0		8-65	Dry	
	8-63	105.8	12S/9E-30M1	1-49	51.6	
	10-63	104.9		1-66	45.7	
	3-64	101.4	12S/10E-26M1	-99	flowing	4gpm
	3-65	95.3		1-49	0	
	2-68	115.0		9-62	3.4	
	3-68	115.0		5-80	flowing	1.5 gpm
12S/9E-23D1	12-53	64.2	12S/10E-34G1	1-49	27.0	
	2-54	65.8		9-62	21.6	
	11-54	64.6	14S/10E-25G1	4-49	112.4	
	3-55	129.0		11-60	Dry	
	11-55	64.9	14S/10E-25G2	4-49	115.0	
	3-56	64.4		-62	Dry	
	11-56	133.5	14S/10E-25R1	4-49	124.0	
	3-57	65.0		-62	Dry	
	11-57	70.2				
	3-58	66.8				
	11-58	72.5				

APPENDIX 4

LITHOLOGIC LOGS

LITHOLOGIC LOG

Well Location 11S/7E-32Q1

Well Name

Depth-ft

From	To	Material
0	3	Soil
3	6	"Hardpan"
6	12	Sand
12	129	Sand and boulders
129	200	Clay and rock beds
200	217	No record
217	260	"Quicksand"
260	267	Shale, red
267	270	Sand, coarse
270	297	Sand, fine, and clay
297	300	Shale, red
300	309	Gravel, 1/4 inch
309	400	Sand, fine
400	406	Shale, brown
406	418	Gravel, 1/2 to 2 inch
418	441	Sand and clay
441	450	Sand and Gravel, 1/4 to 1/2 inch
450	460	Sand, sloppy
460	463	Clay, yellow

LITHOLOGIC LOG

Well Location 11S/8E-33P1

Well Name

Depth-ft

From	To	Material
0	47	Sand, cobblestones
47	78	Sand, coarse with some gravel, fine
78	86	Sand and boulders
86	93	Conglomerate
93	120	Sand, coarse
120	219	Sand, fine
219	240	Clay, sandy and red
240	260	Sand
260	300	Sand, coarse
300	310	Sand, some clay, blue
310	355	Sand, coarse
355	370	Sand, coarse, boulders
370	380	Sand
380	409	Sand, coarse
409	420	Sand, coarse, boulders
420	436	Clay, sandy and gray

LITHOLOGIC LOG

Well Location 11S/10E-35N1

Well Name

Depth-ft

From	To	Material
0	55	Sand and sandstone
55	66	Clay
66	90	Clay and sand, alternating
90	100	Sand and sandstone capping
100	258	Clay
258	261	Sand and sandstone
261	291	Clay
291	292	Sandstone
292	320	Clay
320	330	Sand and sandstone
330	510	Clay, and sand streaks
510	527	Sand
527	580	Clay and sand
580	602	Clay, soft
602	617	Clay, hard
617	697	Clay
697	809	Clay, and sand streaks

LITHOLOGIC LOG

Well Location 12S/8E-4N2

Well Name

Depth-ft

From	To	Material
0	120	Sand and boulders
120	140	Sand and clay
140	170	Rocks, small and gravel
170	200	Silt
200	240	Silt and clay
240	255	Silt and rock
255	265	Clay

LITHOLOGIC LOG

Well Location 12S/8E-6H1

Well Name

Depth-ft

From	To	Material
0	60	Sand and gravel, fine
60	95	Clay, brown and sandy, boulders
95	105	Sand, fine, light and packed
105	118	Clay, yellow
118	250	Clay, light-brown and sandy, boulders
250	252	Sand, loose and coarse with "birds eye" gravel
252	285	Clay, light-gray with scattered boulders
285	288	Sand, fine and gravel
288	297	Clay, light gray
297	300	Clay, red

LITHOLOGIC LOG

Well Location 12S/8E-6P1

Well Name

Depth-ft		
From	To	Material
0	60	Gravel, fine and boulders
60	120	Sand, hard-packed
120	145	Gravel, large, loosely packed
145	220	Sand and gravel, packed
220	280	Boulders of decomposed granite
280	305	Gravel, large and loosely packed
305	314	Clay, sandy

LITHOLOGIC LOG

Well Location 12S/8E-8K2

Well Name

Depth-ft

From	To	Material
0	113	Sand, coarse and gravel, fine
113	160	Clay and sand
160	180	Clay, hard
180	230	Clay and sand
230	245	Silt
245	263	Clay
263	275	Clay and gravel
275	285	Clay, hard

LITHOLOGIC LOG

Well Location 12S/8E-9H1

Well Name

Depth-ft		
From	To	Material
0	47	Sand, coarse with boulders
47	88	Sand, coarse
88	102	Gravel, cemented
102	105	Sand, coarse
105	112	Boulders
112	115	Sand, coarse
115	130	Sand, coarse, and boulders
130	142	Boulders
142	150	Sand, coarse with thin streaks of clay
150	176	Sand, coarse and gravel

LITHOLOGIC LOG

Well Location 12S/8E-9J2

Well Name

Depth-ft

From	To	Material
0	120	Sand and silt
120	230	Sand, fine and clay
230	270	Silt and sand, fine
270	295	Sand, clean and gravel
295	318	Silt and clay

LITHOLOGIC LOG

Well Location 12S/8E-9J3

Well Name

Depth-ft		
From	To	Material
0	55	Sand and boulders
55	115	Sand, boulders and cobbles
115	190	Sand and gravel
190	193	Clay
193	227	Sand, gravel, and clay
227	250	Sand and gravel

LITHOLOGIC LOG

Well Location 12S/8E-10N1

Well Name

Depth-ft

From	To	Material
0	65	Sand and gravel, dry
65	72	Boulders, dry
72	80	Sand and clay, dry
80	90	Boulders, dry
90	102	Clay, sandy
102	106	Sand, dry and cemented
106	116	Clay and sand
126	141	Gravel, 1½ - 2 inch
141	153	Gravel 2 to 3 inch
153	158	Boulders
158	159	Sand, cemented
159	190	Gravel, 1½ inch and sand, coarse
190	202	Sand, packed, and "sea mud"
202	210	"Quicksand"
210	212	Sand, cemented
212	222	Boulders

LITHOLOGIC LOG

Well Location 12S/8E-15E1

Well Name

Depth-ft		
From	To	Material
0	6	Sand, loose
6	65	Sand and gravel, dry
65	72	Boulders, small
72	80	Clay, dry and sandy
80	90	Boulders, dry
90	102	Clay, sandy
102	106	"Cemented"
106	116	Clay and sand
116	126	Rock, sand, and gravel
126	141	Gravel
141	153	Gravel, 2 to 3 inch
153	158	Boulders
158	159	"Cement"
159	190	Gravel and sand
190	202	Sand, packed, and mud
202	210	"Quicksand"
210	212	Sand, cemented
212	222	Boulders

LITHOLOGIC LOG

Well Location 12S/8E-15N1

Well Name

Depth-ft		
From	To	Material
0	120	Sand and boulders
120	140	Sand and clay
140	170	Rocks, gravel, small
170	200	Silt

LITHOLOGIC LOG

Well Location 12S/8E-15X1

Well Name

Depth-ft		
From	To	Material
0	129	Sand and boulders
129	150	no record

LITHOLOGIC LOG

Well Location 12S/8E-17X1

Well Name

Depth-ft		
From	To	Material
0	2	Soil
2	10	Boulders, gray granite
10	40	Sand and gravel, coarse
40	53	Conglomerate
53	85	Shale, red and waxy
85	95	Shale, brown
95	101	Shale, blue
101	120	Shale, brown and sticky
120	125	Shale, sandy and bronw
125	131	Shale, brown and sticky
131	170	"Quicksand"
170	180	Shale, blue and firm
180	202	Gravel, all colors of quartz pebbles

LITHOLOGIC LOG

Well Location 12S/8E-25X1

Well Name

Depth-ft		
From	To	Material
0	30	Sand and silt
30	75	Clay, brown, waxy and stratified
75	76	Sand
76	79	Clay
79	80	Sand
80	86	Clay
86	87	Clay, blue
87	99	"Quicksand" with mica
99	103	Clay, brown and waxy
103	106	Sand, fine
106	117	"Quicksand" heaving
117	122	Clay, hard, sticky and pink
122	124	Sand, very fine and white
124	128	Shale, sandy, and dark
128	135	Sand, brown
135	148	Sand, fine and white
148	174	Clay, pink and waxy
174	185	Conglomerate, with fossil shells
185	202	Clay, pink
202	215	gravel
215	239	Clay, blue, turning pink with depth
239	245	Gravel and sand

LITHOLOGIC LOG

Well Location 12S/8E-26C1

Well Name

Depth-ft		
From	To	Material
0	94	Gravel, small, and sand, coarse to fine
94	114	Gravel, pea-size, multicolored
114	120	Shale, red and sticky

LITHOLOGIC LOG

Well Location 12S/8E-27F1

Well Name

Depth-ft		
From	To	Material
0	28	Sand and silt
28	50	Conglomerate
50	93	Boulders, granite
93	122	Sand and gravel

LITHOLOGIC LOG

Well Location 12S/9E-22A1

Well Name

Depth-ft

From	To	Material
0	25	Clay, with streaks of fine sand
25	47	Sand, coarse
47	69	Sand, coarse to medium
69	90	Gravel with clay
90	111	Sand, coarse, with streaks of clay
111	133	Sand, coarse with gravel
133	143	Clay
143	153	Sand, coarse
153	166	Clay, with streaks of fine sand
166	174	Gravel
174	194	Clay
194	217	Clay, with streaks of fine sand
217	244	Sand, fine, with streaks of clay
244	270	Clay, with streaks of coarse sand
270	283	Gravel and rocks
283	304	Gravel, sand, coarse with shale
304	316	Clay with gravel, large
316	326	Sand, medium to coarse
326	343	Sand, medium to coarse with clay
343	347	Sand, cemented
347	362	Clay, with streaks of coarse sand
362	379	Sand, coarse with clay
379	390	Clay, with streaks of coarse sand
390	402	Clay
402	445	Clay with sand, coarse

LITHOLOGIC LOG

Well Location 12S/9E-22A2

Well Name Ranch Oasis #1

Depth-ft		
From	To	Material
0	123	fine sand
123	303	clay
303	333	clay and medium sand
333	421	medium and coarse sand
421	620	clay, sometimes streaked or mixed with medium sand
620	655	coarse sand and clay
655	689	cemented sand
689	719	medium sand
719	729	clay

LITHOLOGIC LOG

Well Location 12S/9E-22A3

Well Name Ranch Oasis #3

Depth-ft

From	To	Material
0	20	fine to medium and coarse sand with small streaks
		of clay
20	60	fine to coarse sand and clay
60	124	fine to medium coarse sand with streaks of clay
124	136	red clay
136	216	blue clay with streaks of medium sand
216	254	blue clay with streaks of medium to coarse sand
		with gravel
254	399	medium to coarse sand with some gravel, some
		clay streaks
399	491	medium to coarse sand, some clay streaks
491	503	red clay
503	617	medium to coarse sand and gravel with some small
		clay streaks
617	705	clay with streaks of medium sand
705	760	fine to medium sand with some coarse sand and
		clay streaks
760	775	clay and fine to medium sand with some coarse sand
775	880	red clay
880	957	medium to coarse sand, some clay streaks
957	1105	medium to coarse sand with some fine sand
1105	1142	fine to coarse sand with streaks of clay
1142	1200	fine, medium and coarse sand and clay
1200	1250	clay with small streaks of medium to fine sand

LITHOLOGIC LOG

Well Location 12S/9E-23D1

Well Name

Depth-ft

From	To	Material
0	85	sand and gravel
85	180	clay
180	200	fine sand
200	225	brown clay
225	255	no record
255	360	sand and gravel
360	420	blue and brown clay
420	562	alternating sand and gravel and clay and sandy clay
562	580	clay

LITHOLOGIC LOG

Well Location 12S/9E-23D2

Well Name Ranch Oasis #2

Depth-ft

From	To	Material
0	35	coarse sand
35	75	coarse and fine sand
75	225	clay and sand
225	255	clay and cemented fine sand
255	285	fine sand and some clay
285	605	clay and sand
605	625	clay and some gravel
625	635	sand and gravel
635	675	gravel, sand and some clay

LITHOLOGIC LOG

Well Location 12S/9E-23E1

Well Name Ranch Oasis #5

Depth-ft		
From	To	Material
0	25	fine to medium sand
25	33	clay
33	83	fine, medium and some coarse sand with clay streaks
83	137	clay
137	205	clay with small streaks of sand
205	265	fine, medium and coarse sand
265	292	fine, medium and coarse sand with clay streaks
292	324	medium to coarse sand with small clay streaks
324	386	medium to coarse sand with clay streaks
386	540	fine, medium and coarse sand and clay
540	604	medium to coarse sand with clay streaks
604	635	medium to coarse sand and clay
635	740	clay
740	769	medium to coarse sand with some gravel mixed
769	946	clay
946	977	clay with small streaks of medium to coarse sand
977	1008	clay with streaks of medium to coarse sand
1008	1130	medium to coarse sand with some gravel

LITHOLOGIC LOG

Well Location 12S/9E-25F1

Well Name Ranch Oasis #6

Depth-ft		
From	To	Material
0	115	fine and medium with streaks of coarse sand
115	326	clay with streaks of coarse sand
326	388	medium to coarse sand with streaks of clay
388	511	medium to coarse sand
511	573	clay with streaks of medium to coarse sand
573	604	clay with streaks of fine to medium sand
604	628	clay
628	720	clay and fine to medium and some coarse sand
720	759	medium to coarse sand with streaks of clay
759	790	medium to coarse sand
790	880	clay
880	914	clay with streaks medium to coarse sand
914	956	clay
956	995	clay and medium to coarse sand
995	1008	medium to coarse sand
1008	1038	clay

LITHOLOGIC LOG

Well Location 12S/9E-26D

Well Name Ranch Oasis #4

Depth-ft

From	To	Material
0	30	fine and medium sand with streaks of coarse sand
30	60	fine and medium sand
60	87	fine and medium sand with streaks of coarse sand and clay
87	119	fine, medium and coarse sand with streaks of clay
119	182	fine, medium and coarse sand
182	232	clay
232	374	clay with small streaks of sand
374	394	clay with streaks of medium to coarse sand
394	428	medium to coarse sand and clay
428	459	medium to coarse sand with some clay streaks
459	519	fine, medium and coarse sand
519	615	medium to coarse sand with some gravel and small clay streaks
615	645	clay with streaks of medium to coarse sand
645	690	clay with small streaks of medium to coarse sand
690	706	clay with streaks of fine to medium sand
706	790	clay with fine sand, some medium sand
790	830	fine to medium sand with clay streaks
830	894	fine to medium sand with some streaks of coarse sand and clay
894	950	fine to medium sand with some tight coarse sand
950	1011	fine, medium and coarse sand with clay streaks
1011	1130	clay with streaks of sand

LITHOLOGIC LOG

Well Location 12S/11E-18J1

Well Name LCRP19

Depth-ft

From	To	Material
0	19	Clay, silty, brown and fine sand
19	33	Sand, coarse to very coarse
33	40	Clay, silty, brown
40	65	Sand, medium to very coarse, and very fine gravel
65	116	Clay, silty, brown, and silt, Few streaks of
		gray clay
116	124	Silt, brown, and very fine sand
124	153	Clay, silty, brown, and silt. Few streaks of gray
		clay
153	192	Sand, fine to coarse, and some brown silt
192	212	Clay, silty, brown
212	224	Sand, fine and brown silt
224	277	Clay, silty, brown, and some fine to coarse sand
277	289	Sand, medium to coarse
289	302	Clay, silty, brown and fine sand
302	332	Sand, partly cemented, fine to medium and brown
		silty clay
332	405	sand, fine to very coarse, small amount of very
		fine gravel
405	438	Clay, silty, brown, and some gray clay
438	470	Sand, fine to very coarse, layers of brown silty
		clay
470	488	Sand, fine to very coarse, small amount of very
m		fine gravel
488	528	Clay, silty, brown
528	557	Sand, fine to coarse
557	600	Clay, silty, brown and gray, layers of fine to
		medium sand
600	668	Sand, fine to very coarse, partly cemented layers
		brown and gray silty clay

LITHOLOGIC LOG

Well Location 12S/11E-18J1 (Cont'd)

Well Name LCRP19

Depth-ft

From	To	Material
668	700	Clay, silty, brown and gray, and layers of medium to coarse sand
700	725	Sand, fine to very coarse
725	743	Clay, brown and gray, silty
743	768	Sand, fine to coarse, and some clay
768	813	Clay, gray-brown, silty, and small amount of olive-green clay
813	835	Sand, fine and gray-brown clay
835	868	Sand, fine to very coarse, and some clay
868	879	Clay, gray-brown, silty
879	888	Sand, fine to coarse
888	903	Clay, gray and brown, silty
903	924	Sand, fine to coarse, and silt
924	931	Clay, gray and brown, silty
931	959	Sand, fine to coarse, and gray-brown silty clay

LITHOLOGIC LOG

Well Location 12S/11E-36K

Well Name

Depth-ft

From	To	Material
0	75	Sand, surface, and clay
75	114	Clay
114	118	Sandstone
118	163	Clay
163	176	Clay streaks, and sand
176	178	rock
178	187	Clay
187	190	Sand
190	194	Clay
194	197	Sand, medium
197	206	Clay
206	218	Clay, and medium sand streaks
218	242	Sand, medium, and clay
242	260	Clay
260	265	Sand, medium
265	267	Clay
267	294	Sand, medium, and clay streaks
294	295	Rock
295	357	Sand, medium to coarse, and clay
357	365	Clay
365	417	Sand, fine, and pebbles; some clay streaks
417	426	Clay
426	428	Boulders
428	432	Clay
432	438	Mix, fine to coarse
438	446	Clay
446	450	Boulders
450	457	Sand, fine to medium, clay streaks
457	503	Clay and fine sand

LITHOLOGIC LOG

Well Location 14S/11E-32R

Well Name LCRP8

Depth-ft

From	To	Material
0	10	Sand, very fine to very coarse; some brown silt
10	30	Sand, very coarse; and very fine subangular gravel
30	60	Clay, brown, some gray; some silt and very fine sand
60	90	Silt, light brown; very fine sand
90	110	Clay, brown; silt and very fine to fine sand, bits of wood
110	150	Sand, very fine to very coarse, angular, some subangular gravel
150	170	Sand, very coarse to coarse; very fine to fine subangular gravel
170	180	Sand, fine, very fine and coarse; some brown clay
180	220	Clay, brown, some gray; brown silty clay and sand
220	230	Sand, very fine to coarse
230	255	Sand, fine, very fine, cemented; light brown silt
255	280	Clay, brown, light brown silty clay; pieces of carbonized wood
280	315	Clay, brown, sandy; few gray streaks; some silt and sand
315	335	Sand, medium to very coarse; silt; very fine sand
335	345	Clay, brown; fine to coarse sand
345	355	Sand, very fine; some fine to very coarse; very light gray
355	390	Clay, silty, gray; silt and very fine sand
390	410	Sand, very coarse; worn fragments of pelecypods and oysters
410	415	Sand, coarse to very coarse, some very fine subangular gravel
415	435	Clay, brown, silty; fine to very coarse sand
435	445	Sand, coarse, fine to medium; silt, worn Pecten fragments

LITHOLOGIC LOG

Well Location 14S/11E-32R (Cont'd)

Well Name LCRP8

Depth-ft

From	To	Material
445	490	Gravel (50%) very fine to fine; very coarse sand; some silty clay
490	560	Sand, fine to very coarse; small amount very fine gravel
560	575	Clay, silty, light-brown and gray; very fine to coarse sand
575	590	Sand, very fine; some coarse; light-brown silty clay
590	605	Clay, silty, light-gray; light brown silt; very fine sand
605	615	Silt, light-brown; silty clay; few very fine subangular pebbles
615	645	Sand, medium to very coarse; very fine to fine gravel (25%); silty clay
645	675	Clay, silty, light-brown and gray; light-brown silt; very fine to fine sand
675	700	Sand, very fine to coarse
700	715	Clay, brown; fine sand and silt
715	755	Sand, very fine and fine, partly cemented
755	775	Clay brown; silty clay; silt
775	805	Sand, fine; some coarse and very coarse; partly cemented
805	830	Clay, brown and silty clay and silt
830	870	Sand, fine to coarse; silt; some light-brown clay
870	895	Sand, very coarse, some fine to coarse
895	965	Sand, coarse to very coarse; some brown and yellow-brown clay
965	985	Clay, reddish-brown and gray; medium to very coarse cemented sand

APPENDIX 5

WATER QUALITY DATA

WATER QUALITY ANALYSES

LOCATION	11S/7E-17X1	11S/7E-20P1	11S/7E-20P1	11S/7E-20P1
NAME				
DATE	12-17	3-53	1-54	3-58
TDS (mg/l)	1220	1670	1340	1540
Na	306	242	225	265
K		8	10	17
Ca	80	208	172	175
Mg	20	79	33	51
Cl	206	457	250	288
SO_4	518	625	596	684
HCO_3	141	111	108	110
CO_3				
F				0.2
NO_3			5.4	3.9
B				
Fe	0.2			
Mn				
SiO_2	23			
CO_2				
total hard.	282	844	565	647
cond. (mhos/cm)			2100	2290
pH			7.8	7.8

WATER QUALITY ANALYSES

LOCATION	11S/7E-30K2	11S/7E-32Q1	11S/8E-33P1	11S/9E-2B1
NAME				
DATE	2-53	1-54	12-60	5-67
TDS (mg/1)	381	308	1200	2256
Na	110	89	283	860
K	6	4.6		6
Ca	22	15	44	
Mg	2	0.6	5	
Cl	88	62	302	960
SO_4	100	82		119
HCO_3	88	52		459
CO_3				
F			10	3.4
NO_3	10	29		1.1
B				6.6
Fe				
Mn				
SiO_2				
CO_2				
total hard.	63	40	130	
cond. (mhos/cm)	676	550		3932
pH	7.7	8.2	7.9	8.1

WATER QUALITY ANALYSES

LOCATION	12S/8E- 6P1	12S/8E- 8K1	12S/8E- 9J1	12S/8E- 9J3
NAME				
DATE	1-54	1-54	1-49	9-59
TDS (mg/l)	337	365	1520	405
Na	109	112	366	137
K	4.1	3.5		
Ca	16	20	130	10
Mg	1.6	3.3	21	2
Cl	116	106	348	128
SO_4	40	62	595	96
HCO_3	102	118	122	
CO_3				
F				5
NO_3	0.2	0.5		0.5
B			0.9	
Fe				0.1
Mn				
SiO_2				26
CO_2				
total hard.	47	64	411	33
cond. (mhos/cm)	639	692	2430	717
pH	7.8	7.9		8.3

WATER QUALITY ANALYSES

LOCATION	12S/8E-10E2	12S/8E-10N1	12S/8E-10N1	12S/8E-10N1
NAME				
DATE	3-60	4-52	1-54	3-60
TDS (mg/l)	1530	663	713	1270
Na	448	220	232	384
K	9.4	3.9	3.8	5.1
Ca	67	19	20	50
Mg	7	2	1.8	7
Cl	340	185	185	289
SO_4	565	178	232	452
HCO_3	113	93	78	101
CO_3				
F	4.8	8.0		5.3
NO_3	1.9	1	0.1	1.9
B	1.2			1.1
Fe				
Mn				
SiO_2	31			28
CO_2				
total hard.	196	56	57	154
cond. (mhos/cm)	2460	1020	1210	1970
pH	7.8	8.1	8.0	7.7

WATER QUALITY ANALYSES

LOCATION	12S/8E- 15K1	12S /8E- 15R1	12S/8E- 16R1	12S/8E- 22E1
NAME				
DATE	8-64			1-54
TDS (mg/l)		1670	456	538
Na	469	482		177
K				3.4
Ca	102	81	12	16
Mg		10	18	1.8
Cl	330	365	113	147
SO_4		650	85	145
HCO_3		116		96
CO_3				
F		2.5	2.2	
NO_3			0.2	0.3
B				
Fe				
Mn				
SiO_2		24		
CO_2				
total hard.	254	244	104	47
cond. (mhos/cm)	2550	2640		936
pH		7.6	7.7	7.7

WATER QUALITY ANALYSES

LOCATION	12S/8E-22E1	12S/8E-22E1	12S/8E-22E2	12S/8E-22G1
NAME				
DATE	5-60	8-63	5-60	8-63
TDS (mg/l)	569	523	498	1120
Na	186	171	186	309
K	3.5		4.0	
Ca	18	18	18	76
Mg	1.0	0.7	1.0	7.4
Cl	145	145	145	335
SO_4	117	125	117	325
HCO_3	146	72	120	88
CO_3				
F	5.3	4.8	5.3	3.8
NO_3	3.1		3.1	
B	0.6		0.6	
Fe				
Mn				
SiO_2	18	20	18	24
CO_2				
total hard.	49	48	49	220
cond. (mhos/cm)	890	911	890	1870
pH	8.2	7.5	8.2	7.6

WATER QUALITY ANALYSES

LOCATION	12S/8E-22K1	12S/8E-23F1	12S/8E-23G1	12S/8E-24Q1
NAME				
DATE	8-63	8-63	8-63	1-54
TDS (mg/l)	476	655	1510	1470
Na	167	85	420	385
K				10
Ca	14	32	82	97
Mg	2	4	15	14
Cl	146	217	350	335
SO_4	140	308	575	590
HCO_3			96	76
CO_3				
F	5.5	5.5	4.0	
NO_3	0.6	2.7		0.6
B	0.4	0.6		
Fe	0.02	0.01		
Mn				
SiO_2			20	
CO_2				
total hard.	43	96	268	300
cond. (mhos/cm)			2410	2280
pH	8.2	8.1	7.6	7.5

WATER QUALITY ANALYSES

LOCATION	12S/8E-24Q1	12/8E-27F1	12S/9E-21N1	12S/9E-22A1
NAME				
DATE	8/63	1/49	1/72	7/63
TDS (mg/l)	1340	449		5910
Na	361	62	1360	1360
K			15	
Ca	89	79	380	450
Mg	15	16		184
Cl	323	92	1830	2000
SO_4	548	103		1850
HCO_3		195		96
CO_3				
F	2.5			1.3
NO_3	1.2			
B	1.1	0.7		
Fe				
Mn				
SiO_2				19
CO_2				
total hard.	284	263		1880
cond. (mhos/cm)		740		8630
pH	7.9		7.4	7.2

WATER QUALITY ANALYSES

LOCATION	12S/9E 22A2	12S/9E 22A2	12S/9E 22A2	12S/9E 22A2
NAME	Ranch Oasis #1			
DATE	9-62	7-63	2-65	12-69
TDS (mg/l)	1580	1560	1687	1724
Na	372	383	380	387
K			11	
Ca	157	130	146	153
Mg	23	29	24	26
Cl	578	550	574	568
SO_4	388	400	393	
HCO_3	92	100	98	26
CO_3				
F		0.8	1.2	0.9
NO_3			0.2	
B			0.6	0.7
Fe			0.2	
Mn				
SiO_2	20	19	19	
CO_2				
total hard.	486	442	488	492
cond. (mhos/cm)	2770	2630	2650	2652
pH	7.3	7.4	7.5	7.7

WATER QUALITY ANALYSES

LOCATION	12S/9E-22A2	12S/9E-22A3	12S/9E-22B1	12S/9E-23D1
NAME	Ranch Oasis #1	Ranch Oasis #3		
DATE	8-73	12-69	10-71	3-55
TDS (mg/l)		1806		1840
Na	400	441	550	439
K	9.8		2.1	
Ca	55	113	37	180
Mg		15		37
Cl		596	580	724
SO_4				412
HCO_3				95
CO_3				
F		0.7		
NO_3				
B		0.5		
Fe				
Mn				
SiO_2				
CO_2				
total hard.		344		602
cond. (mhos/cm)		2278		3150
pH	8.5	7.9	8.4	7.8

WATER QUALITY ANALYSES

LOCATION	12S/9E-23D1	12S-9E-23D1	12S/9E-23D1	12S/9E-27B1
NAME				
DATE	9-62	7-63	5-64	1-51
TDS (mg/1)	1650	1734	1771	1840
Na	381	409	425	425
K				
Ca	162	163	144	179
Mg	31	31	36	42
Cl	628	645	667	710
SO_4	388	425	397	431
HCO_3	69	69	81	116
CO_3				
F		1.3	0.9	
NO_3			0.1	
B				
Fe				
Mn				
SiO_2	19	20	2	
CO_2				
total hard.	530	534	508	620
cond. (mhos/cm)	2920	2900	2997	3140
pH	7.3	7.5	8.1	

WATER QUALITY ANALYSES

LOCATION	12S/9E-30M1	12S/10E-26M1	12S/10E-26M1	12S/10E-26M1
NAME		- - - HARPER'S WELL - - -		
DATE	1-49	1-18	1-49	9-62
TDS (mg/l)	482	955	1030	1032
Na	83	270	222	292
K				
Ca	86	56	87	61
Mg	12	13	34	14
Cl	124	336	355	370
SO_4	39	216	284	233
HCO_3	281	98	97	96
CO_3				
F				0.8
NO_3				
B			0.22	
Fe				
Mn				
SiO_2		15		15
CO_2				
total hard.	264	193	356	210
cond. (mhos/cm)	850		1770	1920
pH				7.2

WATER QUALITY ANALYSES

LOCATION	12S/10E-26M1	12S/10E-26M1	12S/10E-34G1	12S/10E-34G1
NAME	- - - HARPER'S WELL - - -			
DATE	1-67	5-67	1-49	9-62
TDS (mg/l)	2050	1024	3920	4520
Na	645	280	1210	1590
K	16	5		
Ca	56	62	140	109
Mg	21	12	67	46
Cl	830	352	2310	2740
SO_4	427	221	25	5
HCO_3	89	105	104	66
CO_3	10			
F	1.3	0.8		
NO_3		1.3		
B		0.7	0.22	
Fe				
Mn				
SiO_2				
CO_2				
total hard.	226	204	495	462
cond. (mhos/cm)		1754		8430
pH	8.5	7.7		6.6

WATER QUALITY ANALYSES

LOCATION	12S/11E-18J1	12S/11E-18J1	12S/11E-18J2	12S/11E-21X1
NAME	LCRP 19	LCRP 19	LCRP 19A	
DATE	5-64	7-64	5-64	11-17
TDS (mg/l)	1440	1420	8420	2090
Na	470	472	2380	705
K	9.4	9.4		
Ca	39	30	348	30
Mg	8.4	9	197	22
Cl	495	498	2950	748
SO_4	296	285	2400	451
HCO_3	200	191	248	207
CO_3				
F	1.8	1.2		
NO_3	0.1	5.2		1.4
B	2.0	2.6		
Fe				
Mn				
SiO_2	18	18	19	26
CO_2				
total hard.	132	112	1680	165
cond. (mhos/cm)	2470	2460	12,600	
pH	8.2	8.4	7.2	

WATER QUALITY ANALYSES

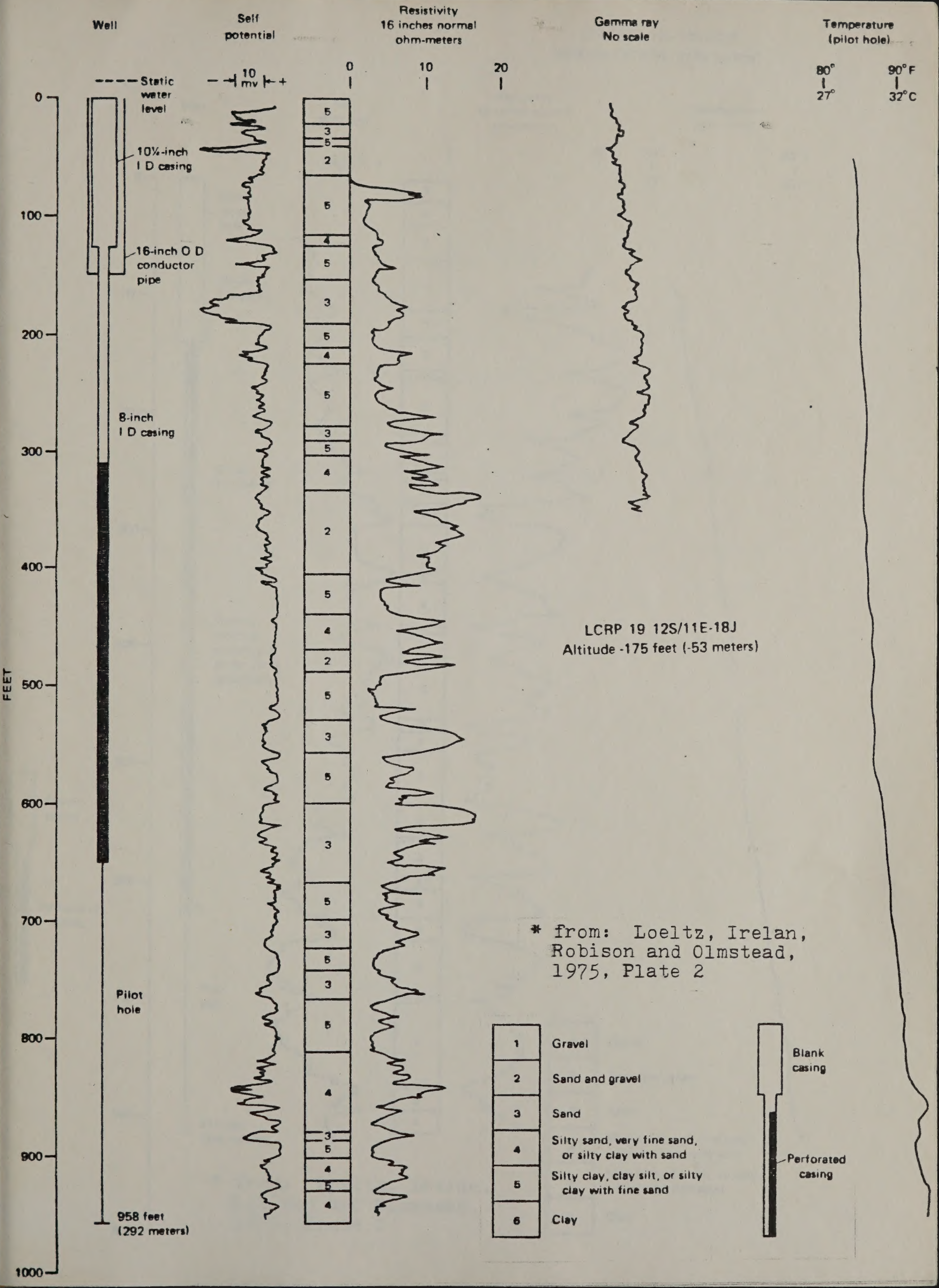
LOCATION	12S/11E-21X1	13S/9E-21X1	13S/9E-24X1	14S/11E-32R1
NAME				LCRP 8
DATE	9-62	1-72	1-49	4-62
TDS (mg/1)	5270		1400	1870
Na	1930	140	526	445
K		0.8		
Ca	28	16	23	133
Mg	32		20	36
Cl	2200	124	280	365
SO_4	800		37	827
HCO_3	567		647	82
CO_3			192 ?	
F				1.4
NO_3				0.2
B			0.22	1.6
Fe				
Mn				
SiO_2				16
CO_2				
total hard.	202		140	480
cond. (mhos/cm)	9180		2390	2800
pH	7.8	8.5		7.5

WATER QUALITY ANALYSES

LOCATION	14S/11E-32R1			
NAME	LCRP 8			
DATE	5-62			
TDS (mg/l)	2140			
Na	510			
K				
Ca	152			
Mg	33			
Cl	318			
SO_4	1080			
HCO_3	64			
CO_3				
F				
NO_3				
B				
Fe				
Mn				
SiO_2	15			
CO_2				
total hard.	515			
cond. (mhos/cm)	2920			
pH	7.7			

APPENDIX 6

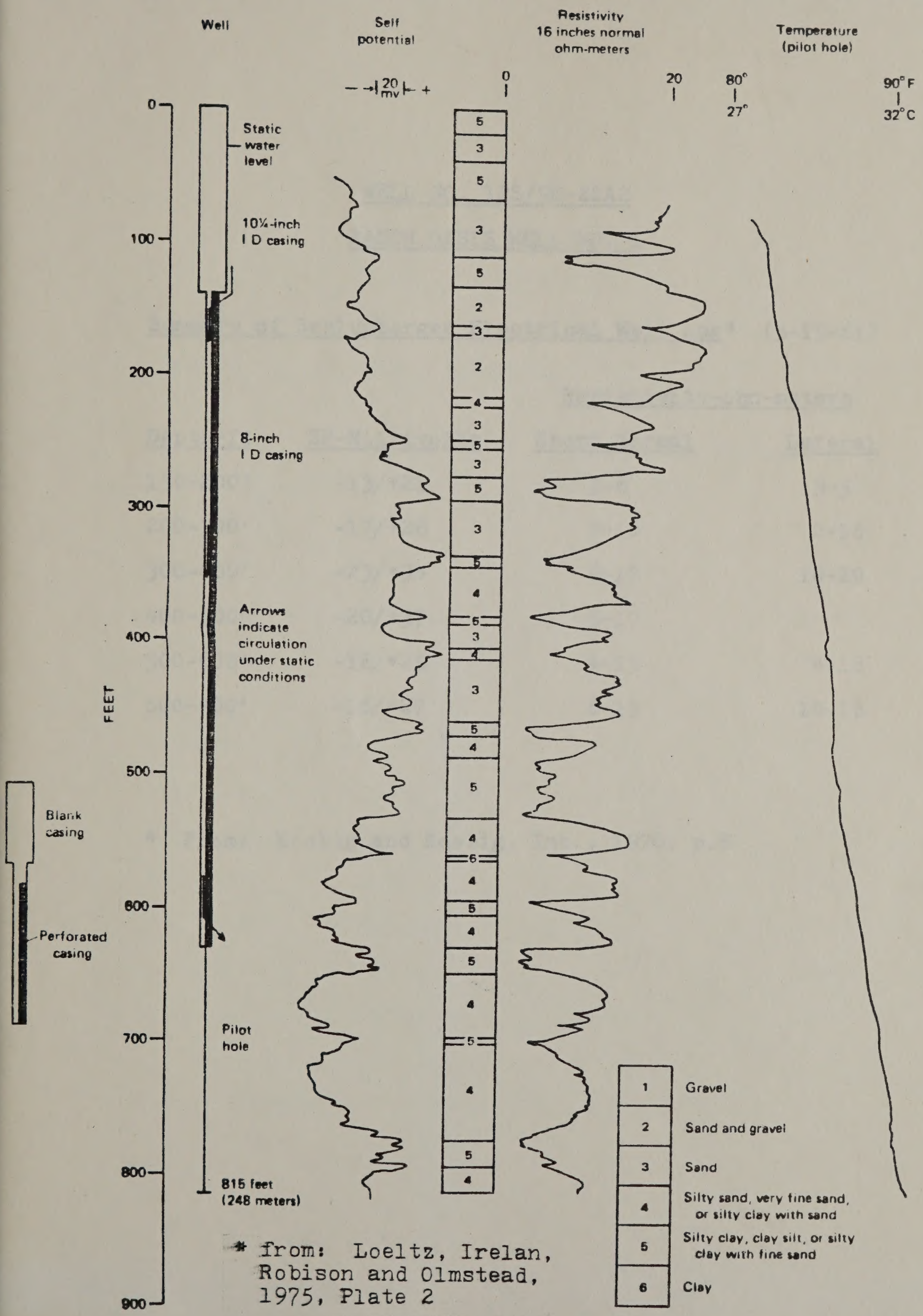
GEOPHYSICAL LOGS



LCRP 19 12S/11E-18J
Altitude -175 feet (-53 meters)

* from: Loeltz, Irelan, Robison and Olmstead, 1975, Plate 2

LCRP 18 16S/18E-32R
Altitude +118 feet (+36 meters)



* from: Loeltz, Irelan, Robison and Olmstead, 1975, Plate 2

WELL NO. 12S/9E-22A2

RANCH OASIS WELL NO. 1

Summary of Schlumberger Electrical Well Log* (5-19-61)

		Resistivity-ohn-meters	
Depth-ft	SP-Millivolts	Short Normal	Lateral
130-200'	-13/+21	3-8	3-5
200-300'	-17/+28	3-16	2-16
300-400'	-23/+34	8-17	10-20
400-500'	-20/+37	5-17	
500-600'	-18/+25	4-15	4-18
600-700'	-16/+27	6-15	10-18

* From: Koebig and Koebig, Inc., 1970, p.8

WELL NO. 12S/9E-22A3

RANCH OASIS WELL NO. 3

Summary of Schlumberger Electrical Well Log * (7-14-67)

		Resistivity-ohm-meters	
Depth-ft	SP-Millivolts	Short Normal	Lateral
130-200'	-10/+6	3-9	3-10
200-300'	-15/+4	4-15	2-21
300-400'	-19/-10	11-18	15-24
400-500'	-17/-2	7-14	8-19
500-600'	-23/-12	4-16	4-19
600-700'	-22/-8	4-17	4-13
700-800	-8/+6	3-14	4-15
800-900'	-6/+2	3-6	2-6
900-1000'	-12/+3	5-12	2-12
1000-1100'	-13/-5	6-16	6-21
1100-1200'	-17/-6	6-18	5-24
1200-1300'	-8/+10	3-12	3-18

* From: Koebig and Koebig, Inc., 1970, p.8-9

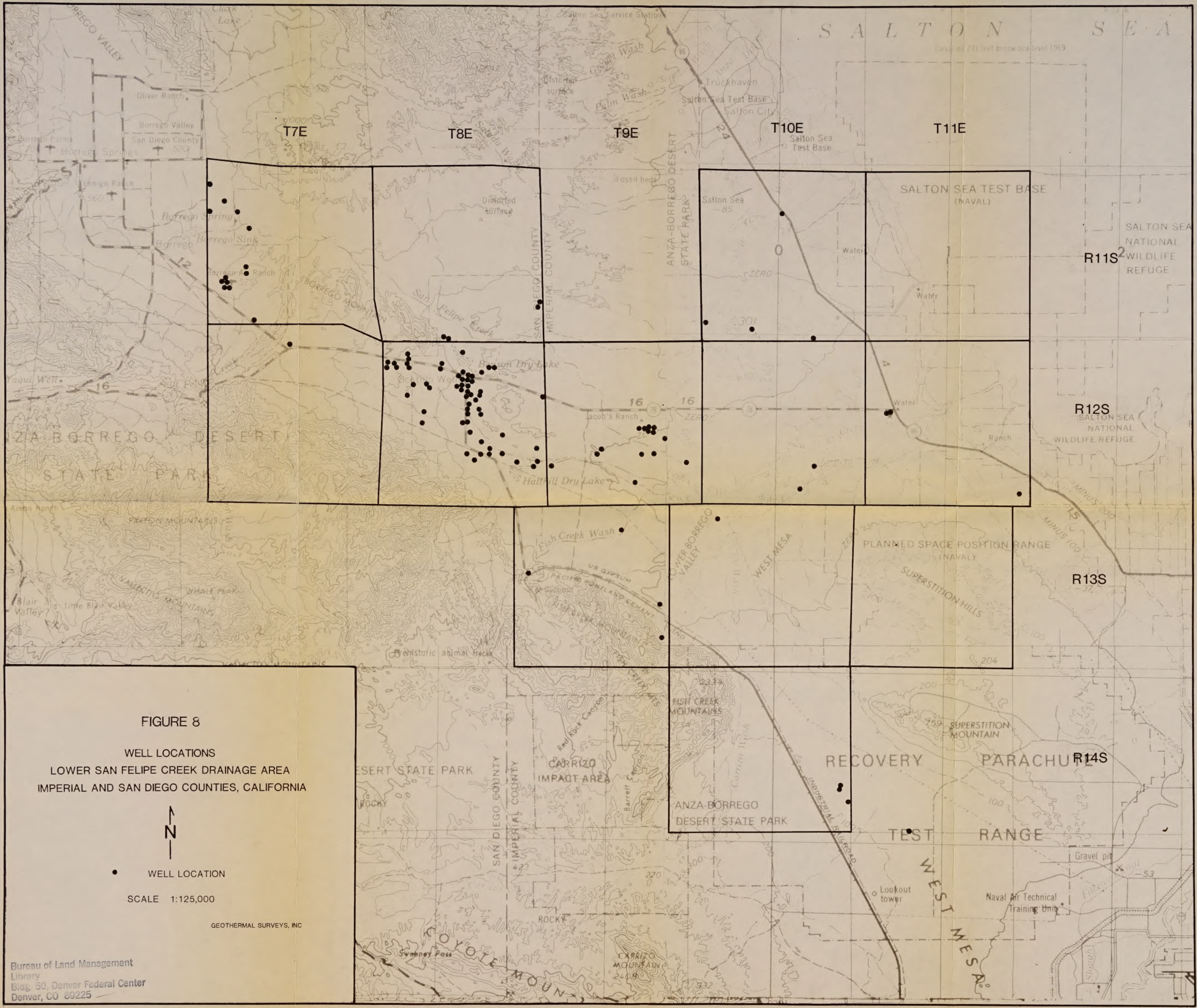


FIGURE 8

WELL LOCATIONS
LOWER SAN FELIPE CREEK DRAINAGE AREA
IMPERIAL AND SAN DIEGO COUNTIES, CALIFORNIA

N

● WELL LOCATION

SCALE 1:125,000

GEOTHERMAL SURVEYS, INC

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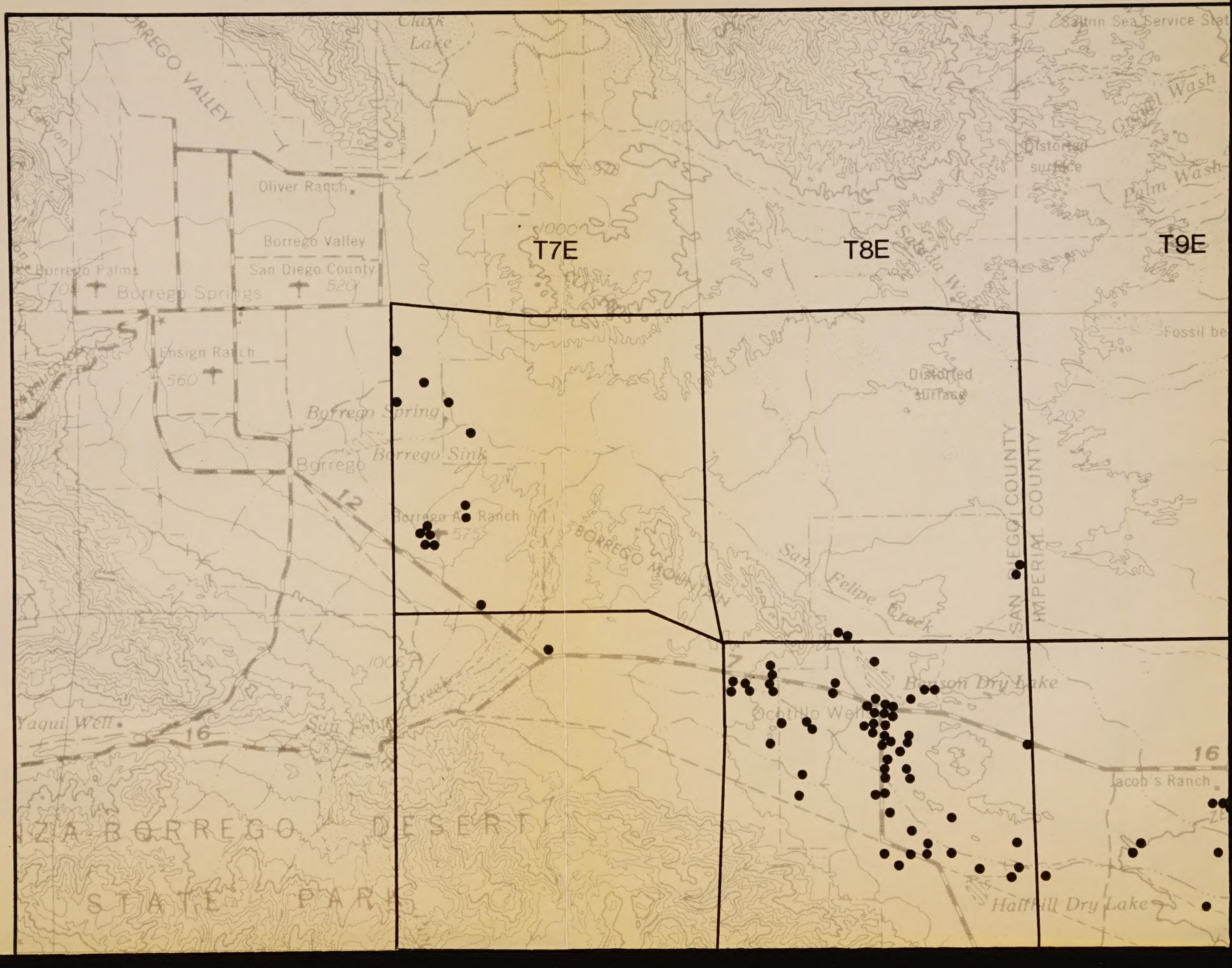
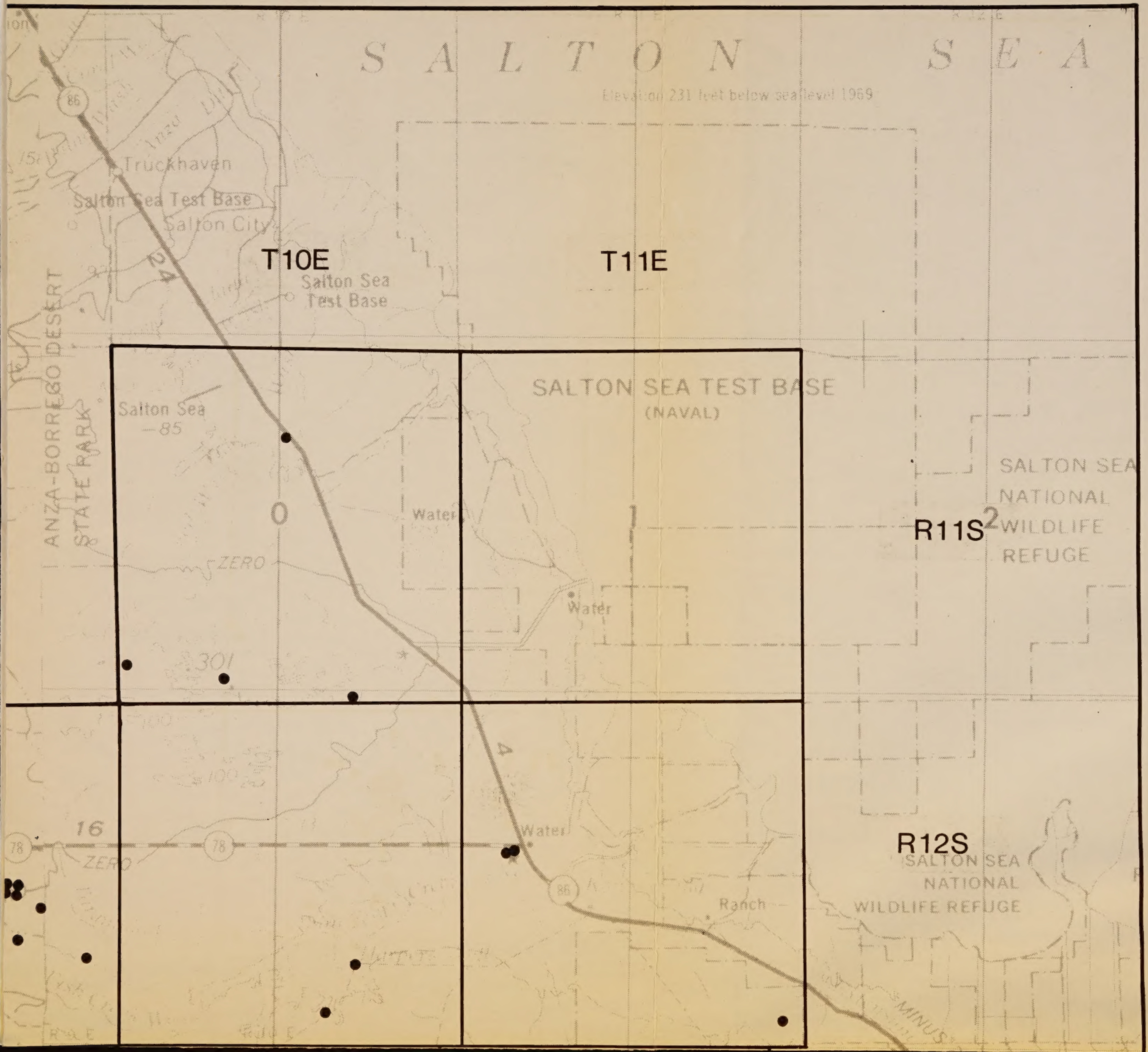

Clark Lake
BORREGO VALLEY
Salton Sea Service Stat
Gravel Wash
Palm Wash
Distorted surface
Oliver Ranch
1000
Borrego Valley
San Diego County
520
Borrego Palms
Borrego Springs
T7E
T8E
T9E
Ensign Ranch
560
Fossil be
Distorted surface
202
Borrego Spring
Borrego Sink
Borrego
12
Borrego Air Ranch
575
BORREGO MOUNTAIN
San Felipe Creek
SAN DIEGO COUNTY
IMPERIAL COUNTY
Benson Dry Lake
Ocotillo Wells
Yaqui Well
16
San Felipe Creek
16
Jacob's Ranch
ANZA BORREGO DESERT
STATE PARK
Halfhill Dry Lake



SALTON SEA
Elevation 231 feet below sea level 1969
Truckhaven
Salton Sea Test Base
Salton City
24
T10E
T11E
Salton Sea Test Base
ANZA-BORREGO DESERT STATE PARK
SALTON SEA TEST BASE (NAVAL)
Salton Sea -85
0
1
2
Water
SALTON SEA NATIONAL WILDLIFE REFUGE
R11S
ZERO
Water
301
4
16
78
78
ZERO
Water
86
86
Ranch
R12S
SALTON SEA NATIONAL WILDLIFE REFUGE
MINUS

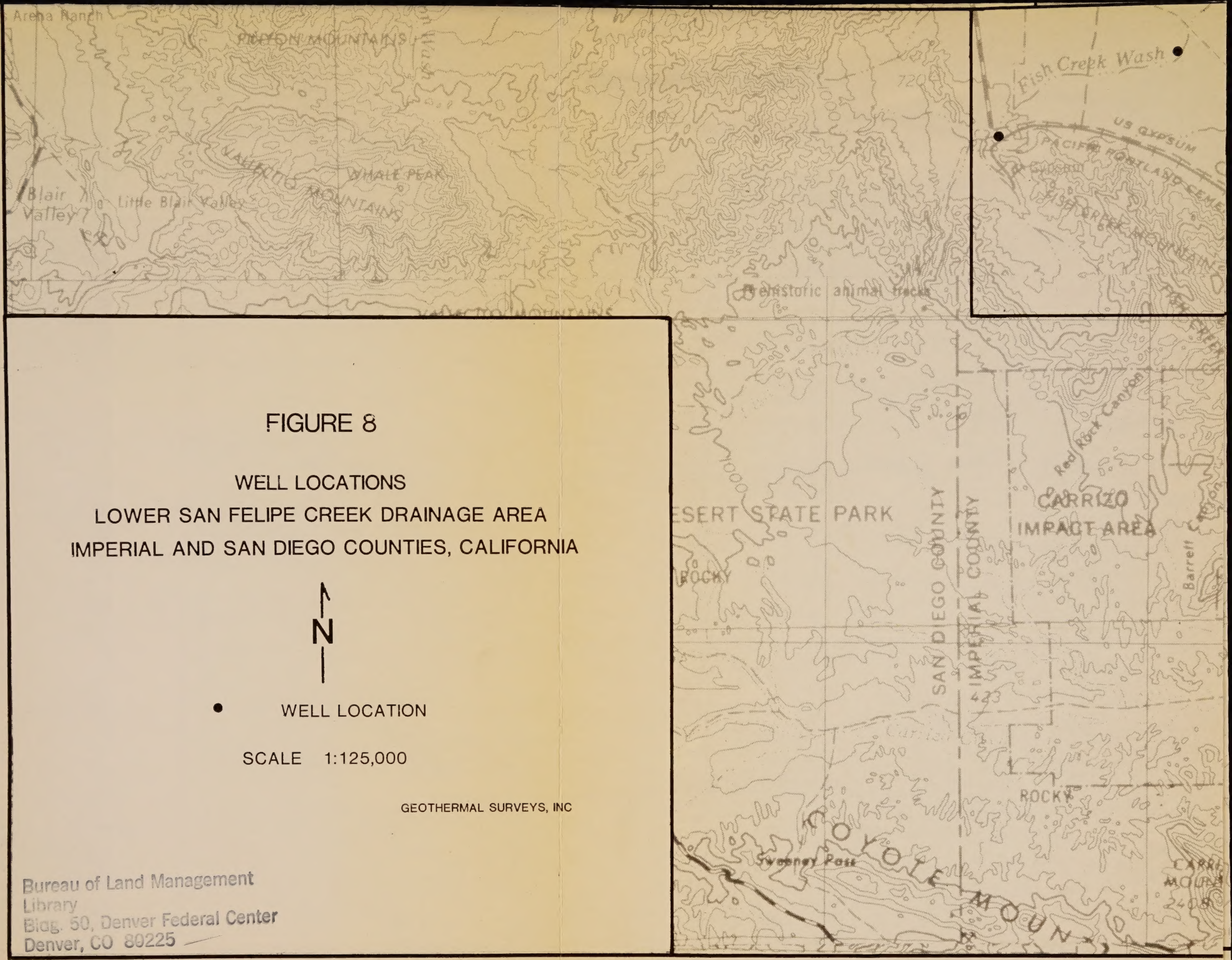


FIGURE 8

WELL LOCATIONS
LOWER SAN FELIPE CREEK DRAINAGE AREA
IMPERIAL AND SAN DIEGO COUNTIES, CALIFORNIA

N

● WELL LOCATION

SCALE 1:125,000

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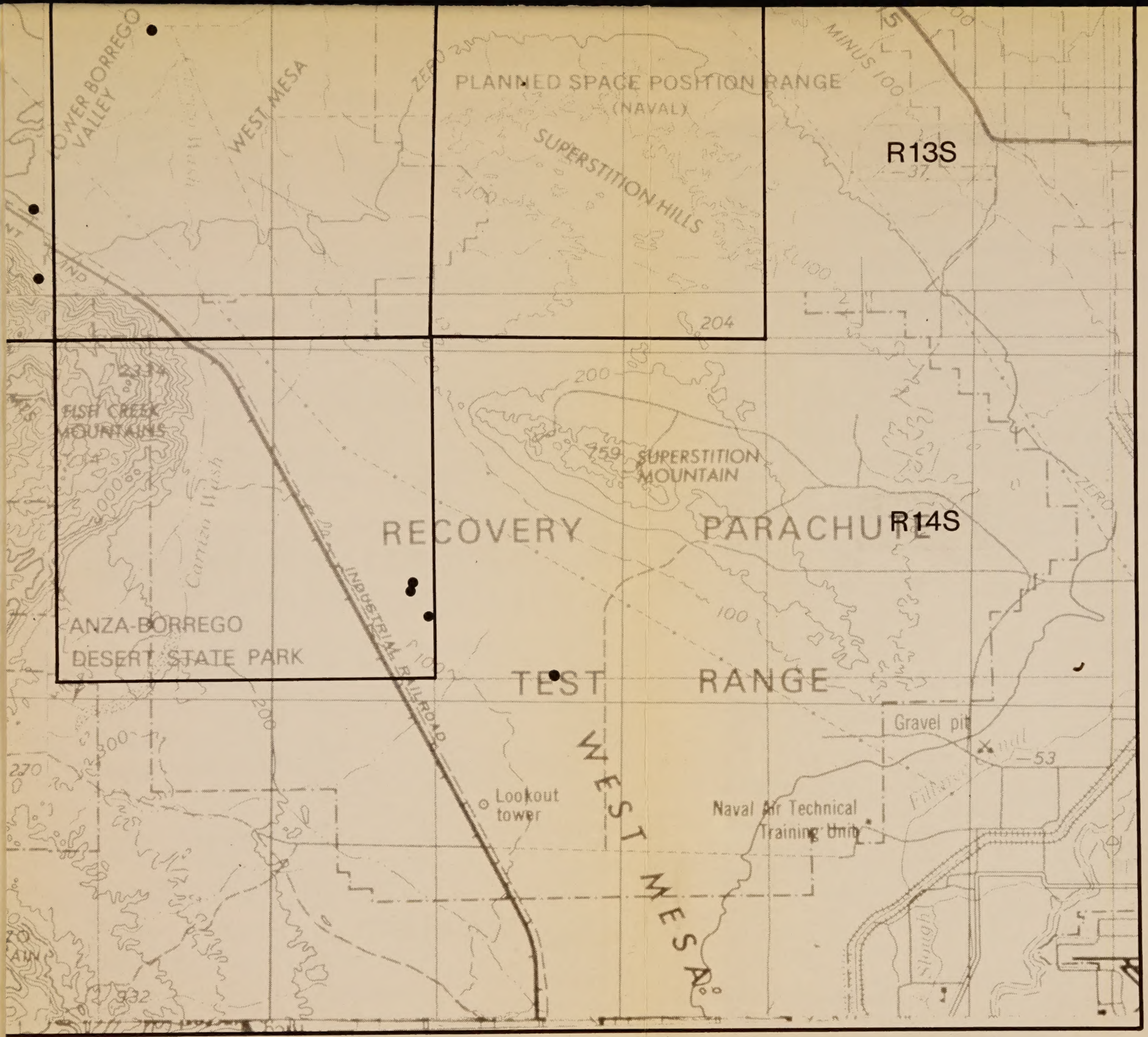
Denver, CO 80225



LOWER BORREGO VALLEY
WEST MESA
ZERO
200
PLANNED SPACE POSITION RANGE
(NAVAL)
SUPERSTITION HILLS
MINUS 100
R13S
37
100
204
2314
FISH CREEK MOUNTAINS
1000
Carrizo Wash
200
159
SUPERSTITION MOUNTAIN
ZERO
R14S
RECOVERY
PARACHUTE
INDUSTRIAL RAILROAD
100
ANZA-BORREGO
DESERT STATE PARK
TEST
RANGE
Gravel pit
Canal
−53
WEST MESA
Lookout tower
Naval Air Technical Training Unit
Slough
200
300
270
932

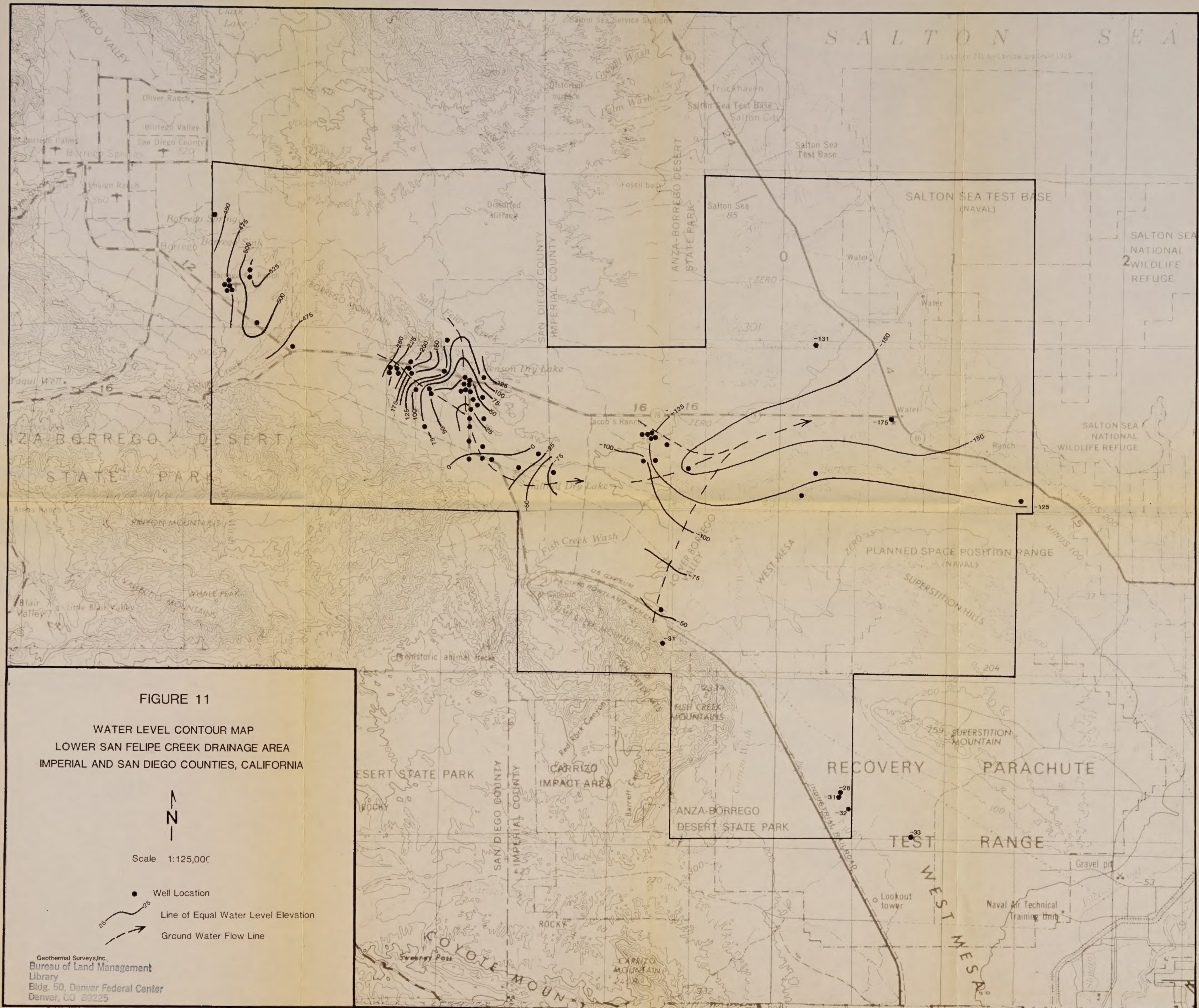


FIGURE 11

WATER LEVEL CONTOUR MAP
LOWER SAN FELIPE CREEK DRAINAGE AREA
IMPERIAL AND SAN DIEGO COUNTIES, CALIFORNIA

Geothermal Surveys,Inc.

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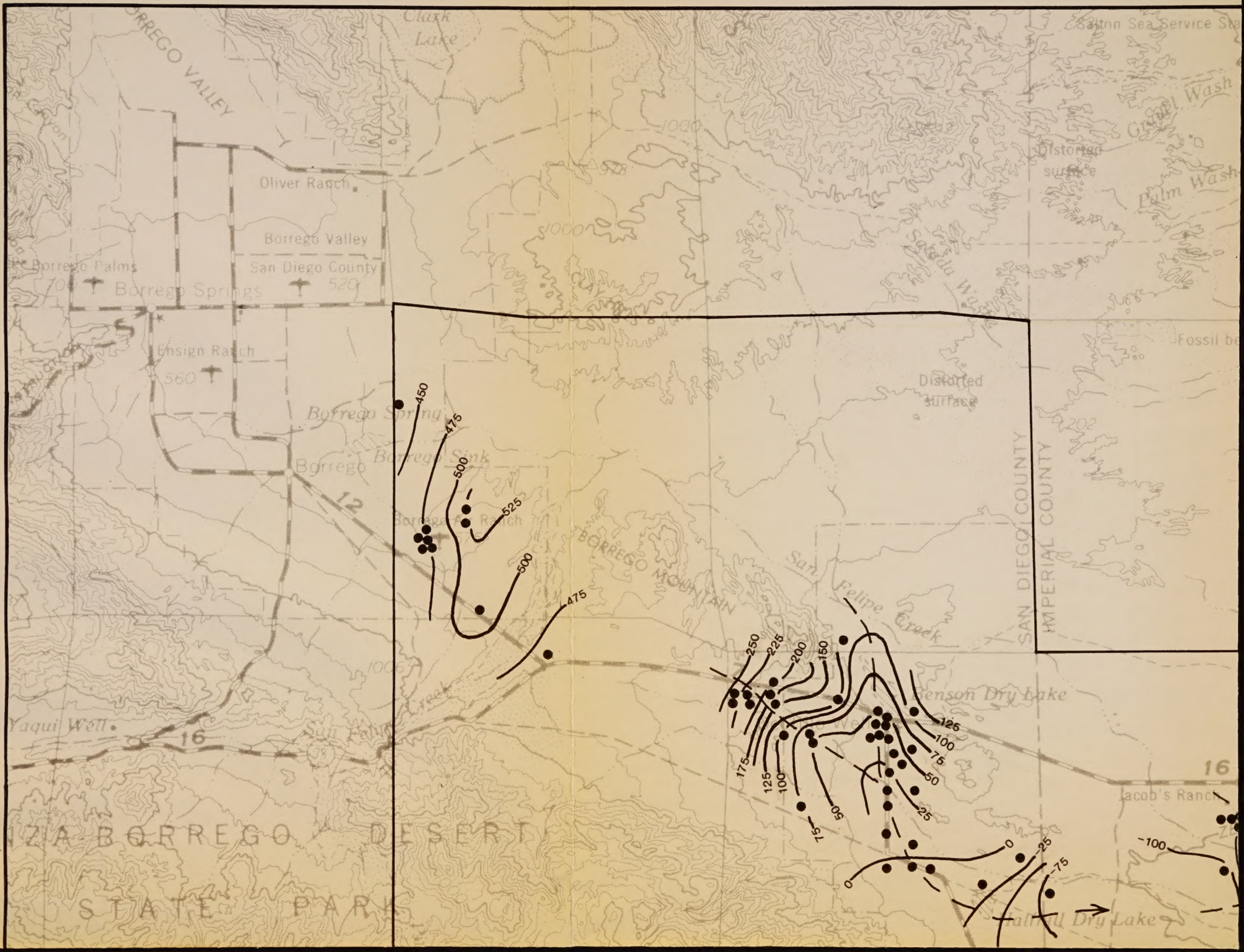
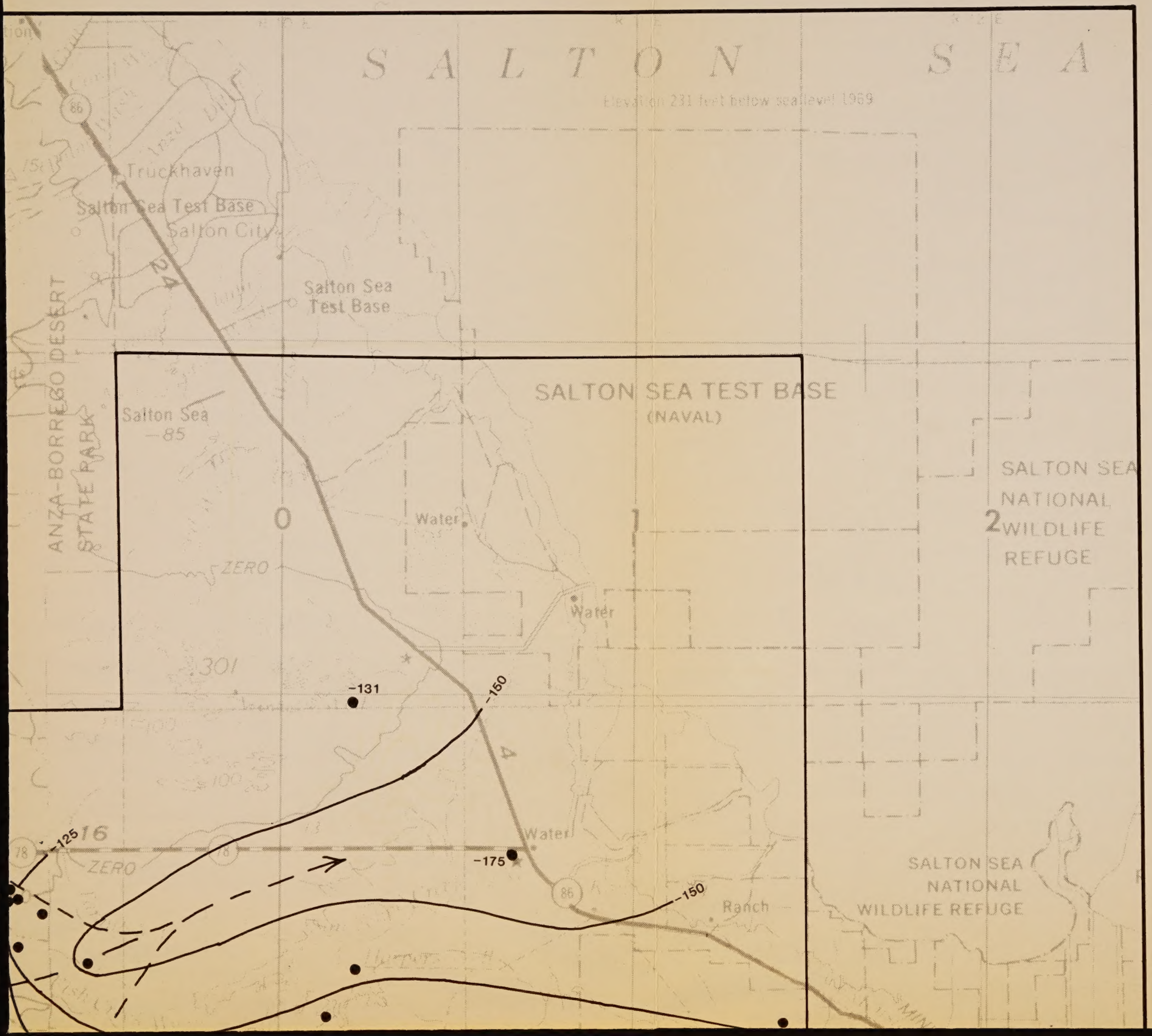

Clark Lake
BORREGO VALLEY
Canyon
Oliver Ranch
Borrego Valley
San Diego County
Borrego Palms
700
Borrego Springs
520
Ensign Ranch
560
Borrego Spring
Borrego Sink
Borrego
12
Borrego Ranch
BORREGO MOUNTAIN
1000
Clay
Salton Sea Service Sta
Gravel Wash
Palm Wash
Distorted surface
Fossil be
Distorted surface
202
SAN DIEGO COUNTY
IMPERIAL COUNTY
San Felipe Creek
Benson Dry Lake
Wells
16
Jacob's Ranch
Yaqui Well
San Felipe
Creek
16
NZA BORREGO DESERT
STATE PARK
Halfhill Dry Lake
450
475
500
525
500
475
250
225
200
150
125
100
75
50
25
175
125
100
75
50
0
0
-25
-75
-100


SALTON SEA
Elevation 231 feet below sea level 1969
86
Truckhaven
Salton Sea Test Base
Salton City
24
Salton Sea
Test Base
ANZA-BORREGO DESERT
STATE PARK
Salton Sea
-85
SALTON SEA TEST BASE
(NAVAL)
0
1
2
SALTON SEA
NATIONAL
WILDLIFE
REFUGE
Water
Water
ZERO
301
-131
-150
4
-125
16
78
78
ZERO
Water
-175
86
-150
Ranch
SALTON SEA
NATIONAL
WILDLIFE REFUGE

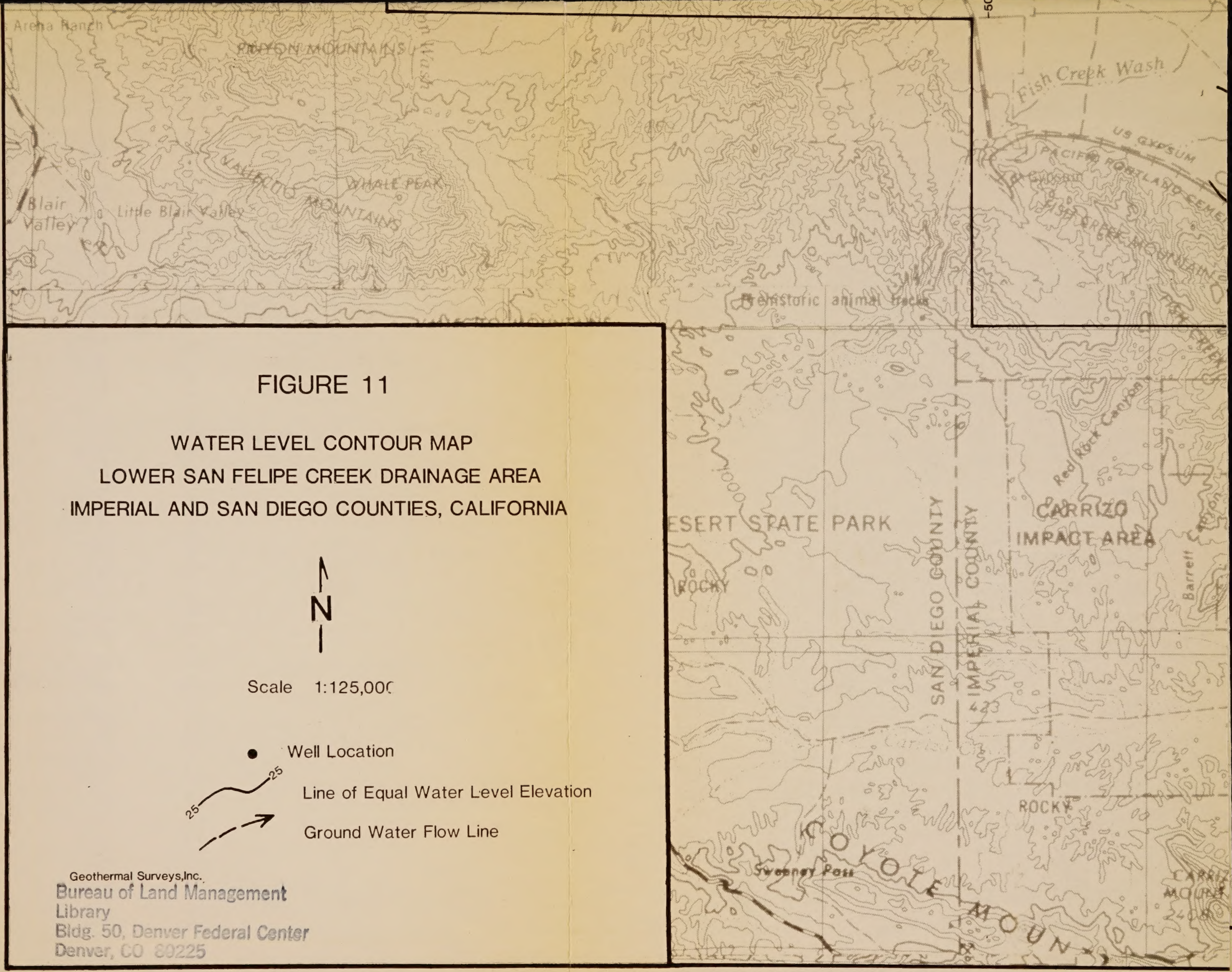


FIGURE 11

WATER LEVEL CONTOUR MAP
LOWER SAN FELIPE CREEK DRAINAGE AREA
IMPERIAL AND SAN DIEGO COUNTIES, CALIFORNIA

N

Scale 1:125,00

● Well Location

25 ~ 25 Line of Equal Water Level Elevation

- - → Ground Water Flow Line

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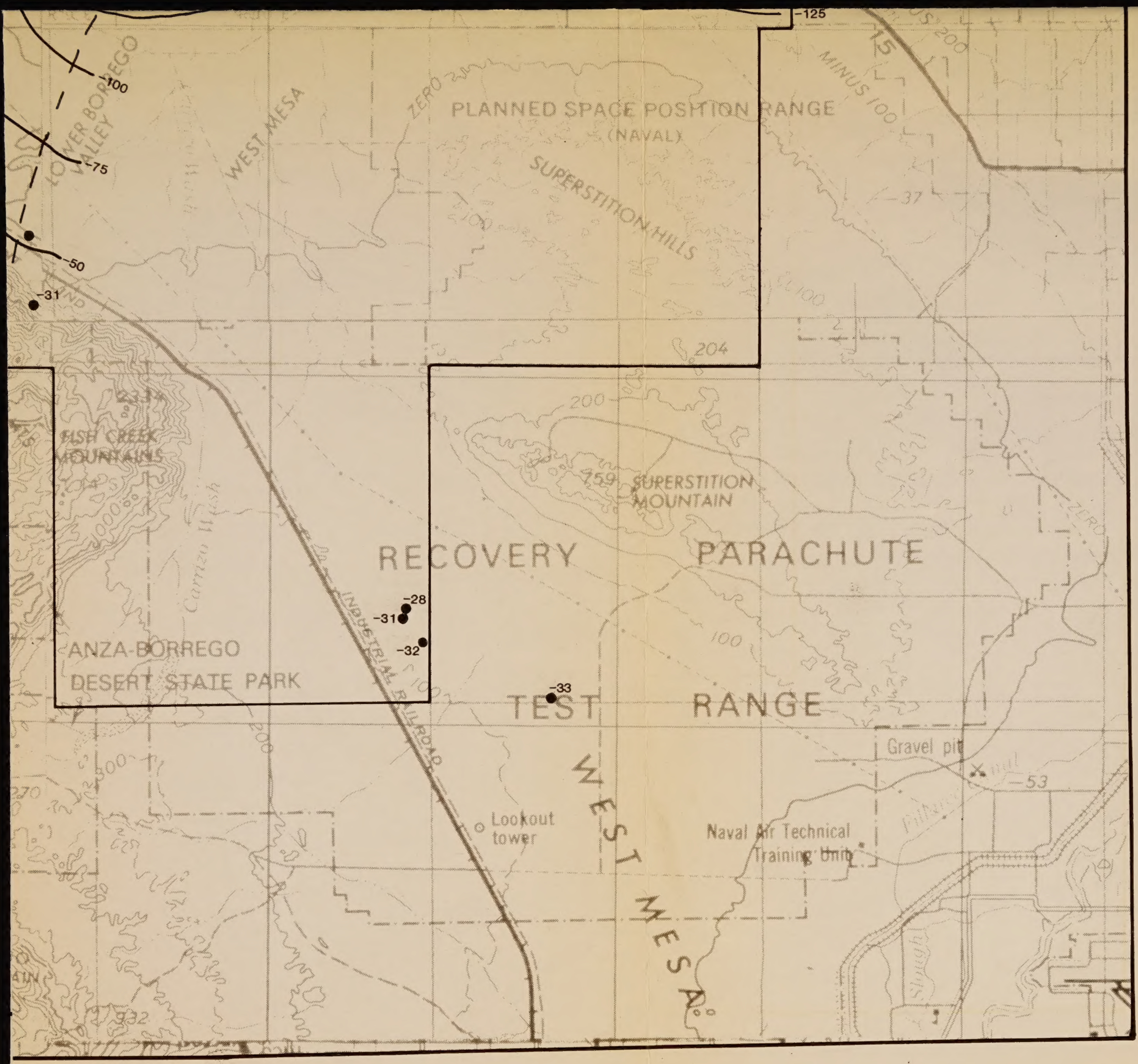
-125
-100
-75
-50
-31
LOWER BORREGO VALLEY
WEST MESA
ZERO
PLANNED SPACE POSITION RANGE
(NAVAL)
SUPERSTITION HILLS
MINUS 200
MINUS 100
15
-37
100
204
200
2314
FISH CREEK MOUNTAINS
Carrizo Wash
759
SUPERSTITION MOUNTAIN
RECOVERY
PARACHUTE
TEST
RANGE
ZERO
-28
-31
-32
-33
INDUSTRIAL RAILROAD
ANZA-BORREGO
DESERT STATE PARK
WEST MESA
Gravel pit
-53
Lookout tower
Naval Air Technical Training Unit
Slough
932

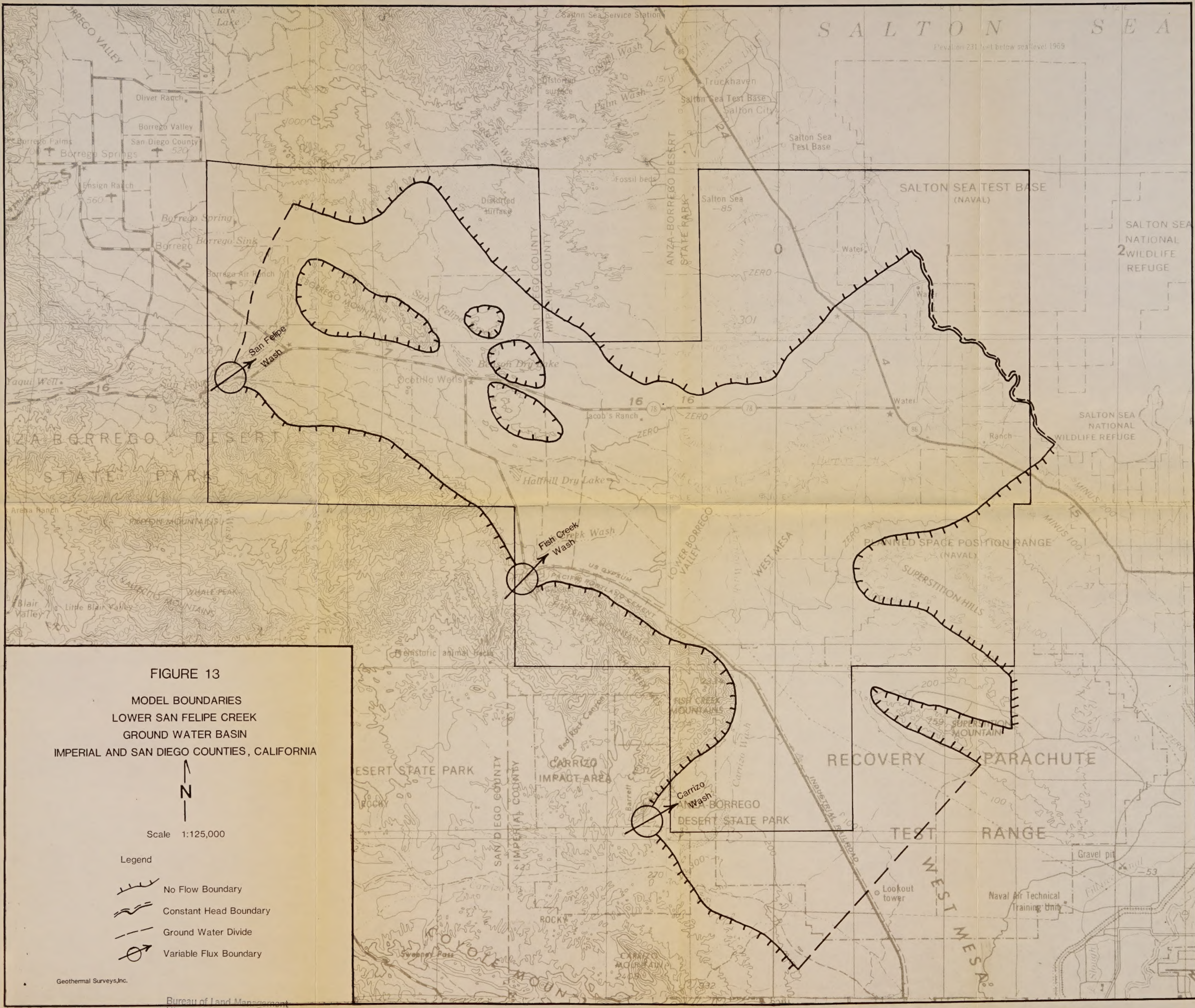

FIGURE 13

MODEL BOUNDARIES
LOWER SAN FELIPE CREEK
GROUND WATER BASIN
IMPERIAL AND SAN DIEGO COUNTIES, CALIFORNIA

N

Scale 1:125,000

Legend

⊥⊥⊥	No Flow Boundary
≈	Constant Head Boundary
– –	Ground Water Divide
⊘	Variable Flux Boundary

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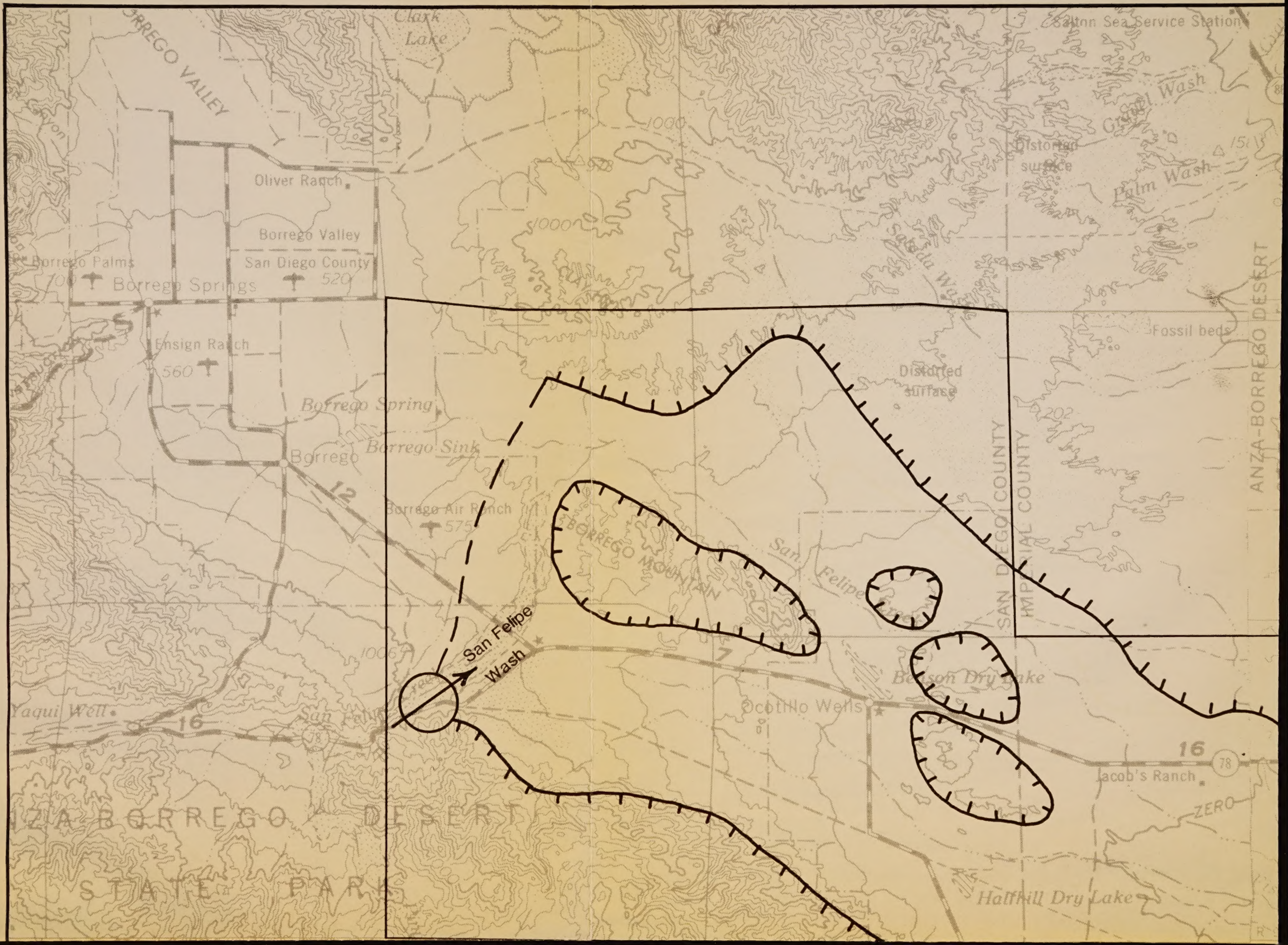
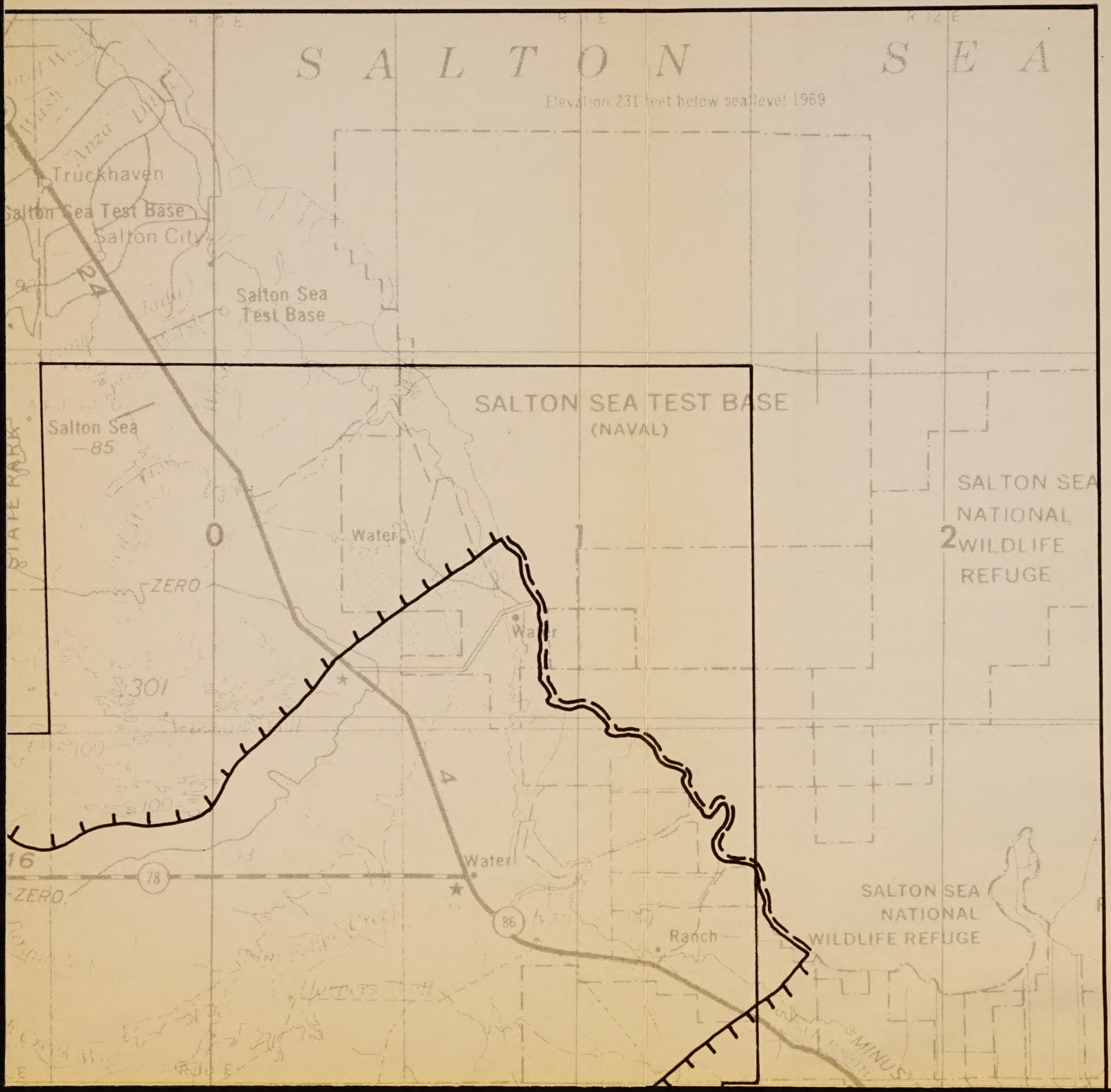

Clark Lake
BORREGO VALLEY
Salton Sea Service Station
Gravel Wash
Distorted surface
Palm Wash
151
86
1000
928
1000
Oliver Ranch
Borrego Valley
San Diego County
Borrego Palms
700
Borrego Springs
520
Ensign Ranch
560
Fossil beds
Distorted surface
202
Borrego Spring
Borrego Sink
Borrego
12
Borrego Air Ranch
575
BORREGO MOUNTAIN
San Felipe Creek
SAN DIEGO COUNTY
IMPERIAL COUNTY
ANZA-BORREGO DESERT
San Felipe Wash
1006
7
Benson Dry Lake
Ocotillo Wells
Yaqui Well
San Felipe
16
78
16
78
Jacob's Ranch
ZERO
ANZA BORREGO DESERT
STATE PARK
Halfhill Dry Lake


R 10 E
R 11 E
R 12 E
SALTON SEA
Elevation 231 feet below sea level 1969
Truckhaven
Salton Sea Test Base
Salton City
24
Salton Sea
Test Base
SALTON SEA TEST BASE
(NAVAL)
Salton Sea
-85
STATE PARK
0
1
2
Water
ZERO
SALTON SEA
NATIONAL
WILDLIFE
REFUGE
301
100
4
16
78
ZERO
Water
86
Ranch
SALTON SEA
NATIONAL
WILDLIFE REFUGE
MINUS
R 10 E

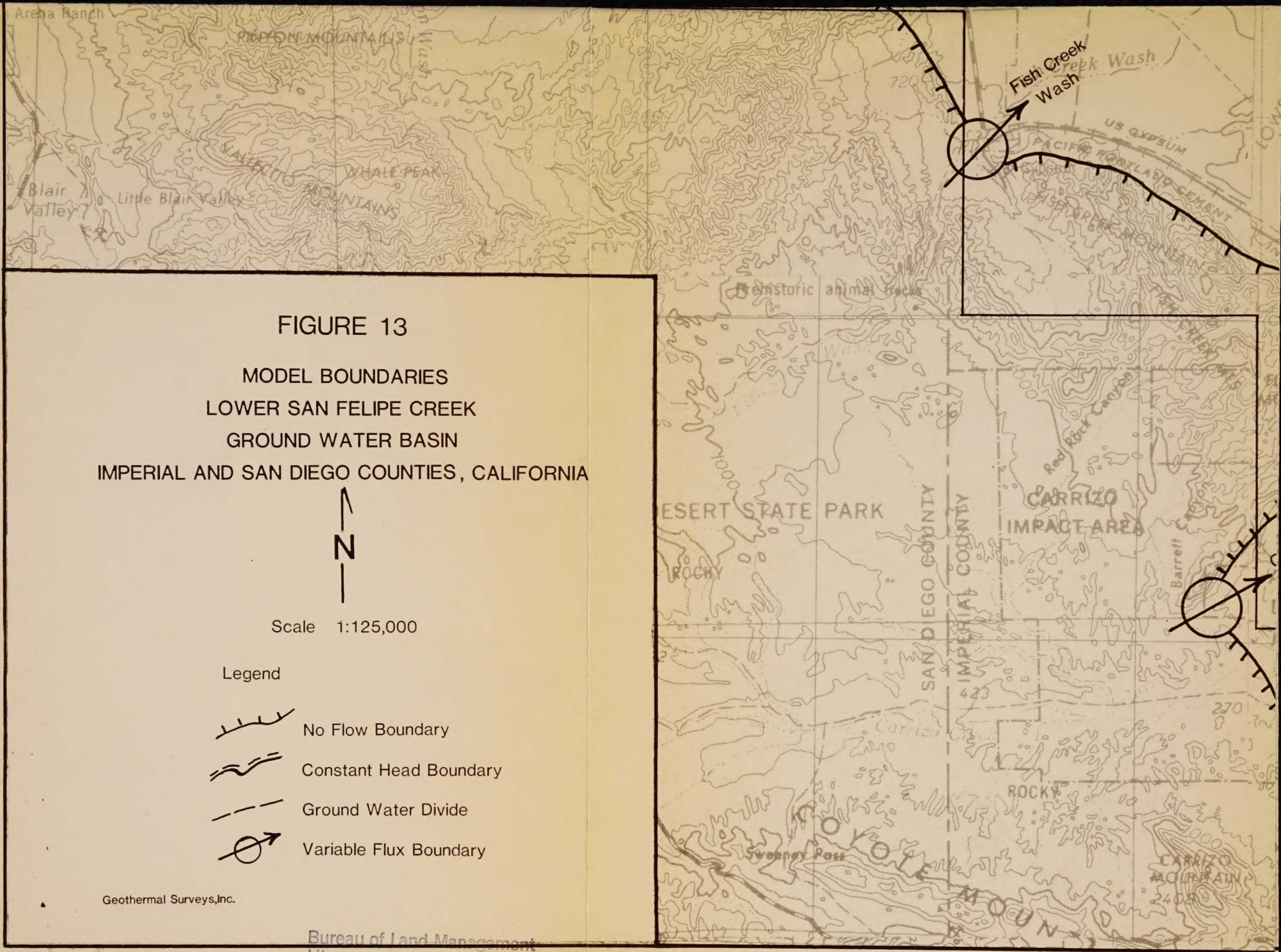


FIGURE 13

MODEL BOUNDARIES
LOWER SAN FELIPE CREEK
GROUND WATER BASIN
IMPERIAL AND SAN DIEGO COUNTIES, CALIFORNIA

N

Scale 1:125,000

Legend

No Flow Boundary

Constant Head Boundary

Ground Water Divide

Variable Flux Boundary

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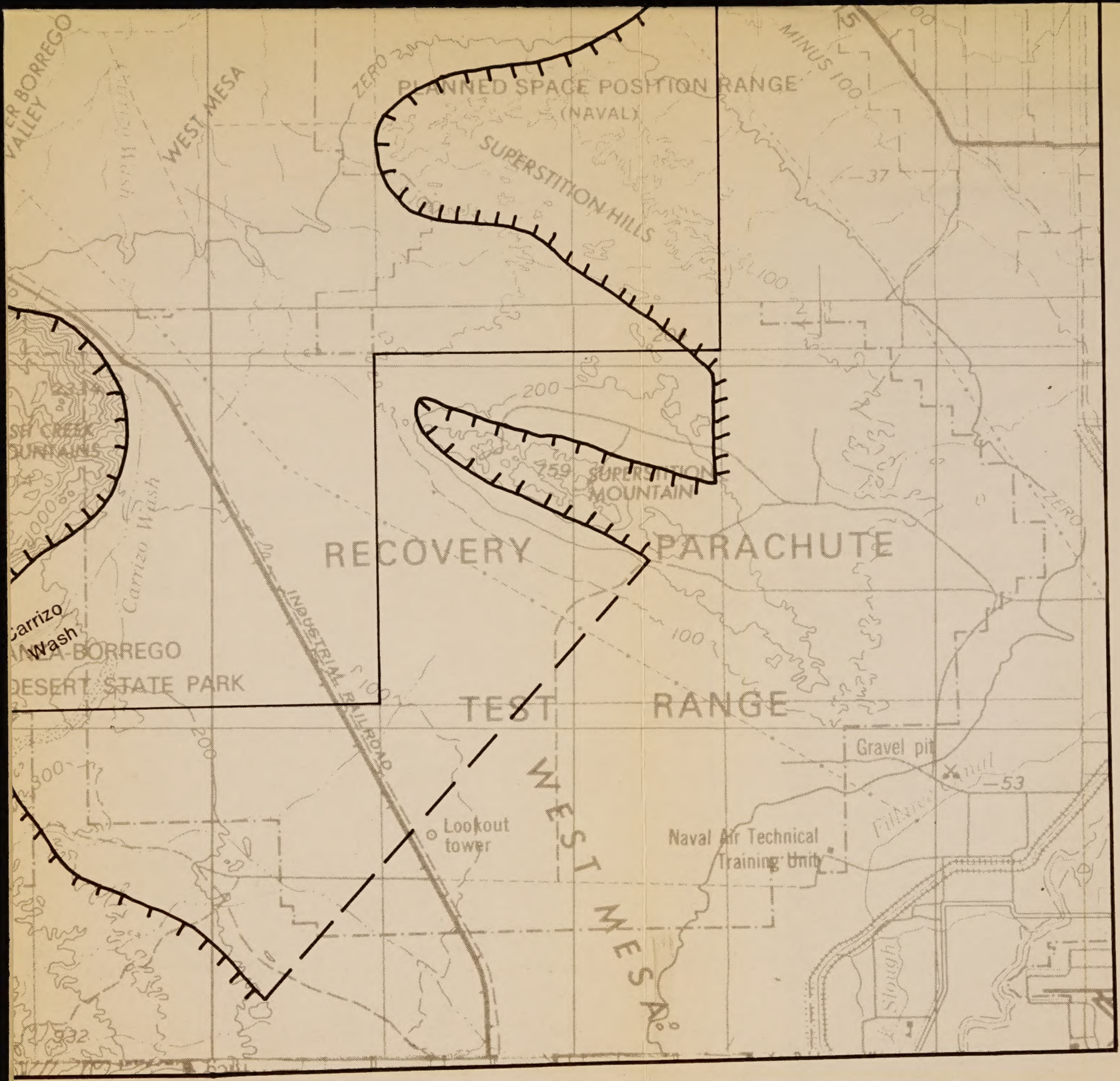
BORREGO VALLEY
WEST MESA
ZERO
PLANNED SPACE POSITION RANGE (NAVAL)
MINUS 100
SUPERSTITION HILLS
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FISH CREEK MOUNTAINS
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SUPERSTITION MOUNTAIN
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ANZA-BORREGO DESERT STATE PARK
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Gravel pit
-53
300
Lookout tower
WEST MESA
Naval Air Technical Training Unit
Slough
932

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	OFFICE	DATE RETURNED

rm 1279–3 (May 1982) (formerly DSC 1279–3a)